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A Half Century of Globular Clusters*

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I

About fifty years ago the globular star clusters made the first of their four major contributions to sidereal knowledge. Beginning in 1895 a series of announcements from Harvard were printed in the *Observatory Circulars* and reprinted in POPULAR ASTRONOMY. "Professor Solon I. Bailey, in charge of the station at Arequipa, . . . has discovered from an examination of the photographs obtained by him of certain globular clusters that they contain an extraordinary number of variable stars," wrote Professor E. C. Pickering, the director of the Observatory. He continued, "The photographs used in this discussion were taken at Arequipa with the 13-inch Boyden telescope. In the cluster of Canes Venatici, Messier 3 (N.G.C. 5272), no less than 87 stars have proved to be variable from the examination of fifteen photographic plates. The change in every case is certain, and has been confirmed independently by Mrs. Fleming and the writer from the examination of six of these plates. Sometimes the variation amounts to two magnitudes or more, and sometimes it does not exceed half a magnitude on the plates which were used for its confirmation. . . . In like manner, from the examination of seventeen plates, Mr. Bailey found forty-six variables in the cluster of Messier 5 (N.G.C. 5904) which were confirmed on five plates."

The discovery of the variability of many stars in globular clusters still remains, fifty years later, one of the most interesting facts of sidereal astronomy. Possibly its most intriguing aspect is the one noted in this first announcement by Pickering, who states, after reporting that a few variables have been found in each of four other globular clusters: "On the other hand, a similar examination of two plates of each of the clusters N.G.C. 6218, 6397, 6626, 6705, and 6752 failed to detect a single variable star, several hundred stars in each case apparently having exactly the same brightness on both plates."

From the beginning, therefore, a striking contrast appears. Two clusters that look alike, and are in the same part of the sky, may differ in that one is without variability and in the other stellar variability is a striking characteristic. In Messier 5, for instance, Pickering noted that "in the entire cluster about 750 stars were examined and forty-six found to be variable, as above stated, so that they form about six per

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cent of the whole. Of all the stars visible to the naked eye less than one per cent are variable." Here is an early indication that the solar neighborhood and a globular star cluster may differ fundamentally in stellar characteristics, for example in susceptibility to stellar variation. A more pronounced difference lies in the magnitudes of giant stars, which is discussed below.

The early explorations were only the beginning of Bailey's discoveries. He examined thirty clusters, finding approximately 500 certain variables. Twenty years later, others began to work in the field, with the result that now in globular clusters about 1300 variables are known, nearly all of which are Cepheids.

Some twenty years after the abundance of variables in clusters became known, the three other contributions that appear to be of special importance began to come to light. They are the following:

The peculiar color-luminosity array for the giant stars (Section V below), which stands out in sharp contrast to the color-luminosity arrangement for stars around the sun and in loose clusters like the Hyades. The phenomenon was initially recognized at Mount Wilson in 1915 with the first determination of blue and yellow magnitudes in the Hercules cluster, Messier 13. The peculiarity was soon verified in half a dozen other globular clusters. Several subsequent observers in the field of color-indices found the same variant on the Russell-Hertzsprung diagram. It suggested[1] the possibility of important evolutionary differences between globular clusters and the solar neighborhood, a situation that has been emphasized in the recent work of Baade and others, who have added velocity criteria to the discriminants of color and absolute magnitude.

The asymmetry of the space distribution of globular star clusters (Section II), with its demonstration of the eccentric place of the solar system in the Milky Way. Before the globular clusters assisted us in finding a correct orientation, the sun and naked-eye stars were commonly held to be at or near the center of the sidereal universe.

The high radial velocities of globular clusters (Section IX), which soon led to the discovery of high speeds for spiral nebulae and for some of the isolated cluster-type variable stars, and thus became a part of the body of evidence for the rotation of our galaxy.

In the following pages a number of more or less isolated results that have also come from the study of globular clusters will be reported, but relatively they are not as valuable in building up the picture of the galactic system and of the metagalaxy as are the four items just described.

[1] *Mt. Wilson Commun.*, 19 and 34, 1916; *Science*, **95**, 580, 1942.

Three of these major contributions from globular clusters are closely linked together. The studies of variable stars in clusters, reinforced by extensive work on Cepheid variables in the Magellanic Clouds and in the galactic system (solar neighborhood), led to knowledge of the surprisingly great distances of most globular star clusters. After globular star clusters had been rather laboriously differentiated from galactic clusters and from spheroidal galaxies, this information on distances was coupled with the data on the peculiar distribution of globular clusters in the sky, and led to the demonstration, and quantitative measurement, of the eccentric position of the sun in the system of clusters. If the sun is off-center with respect to globular clusters, the inference is natural that the sun is also eccentrically located in the overall Milky Way system of stars, since the globular clusters are undoubtedly a part of the galactic system. Thus the Cepheid variable stars and the distribution of globular clusters in the sky were used together to show that the heliocentric view of the stellar system is untenable.

Similarly it was the measures of blue and yellow magnitudes for giant stars in globular clusters combined with the new knowledge of distances, and therefore of absolute stellar magnitudes, that resulted in the setting up of the first color-luminosity array, and therefore in the demonstration that the population of a typical globular cluster is unlike that depicted by the Russell-Hertzsprung diagram for stars in the vicinity of the sun.

II. Number and Distribution over the Sky

The uneven distribution of globular clusters on the surface of the sky attracted little attention in the first two decades of the interval under survey, and still less before then, throughout the eighteenth and early nineteenth centuries when Messier, Méchain, and Sir William Herschel were getting the globular clusters into the catalogues of nebulous objects. After the great distances of some of the clusters became known through the studies of their variable stars, it was recognized that there might be much cosmic significance in the scarcity of globular clusters north of declination $+30°$ and their concentration in and near the southern Milky Way.

The distribution of the ninety-seven now accepted as members of our own galactic system is shown on the Aitoff projection (Figure 1), which differs only in minor details from the charts constructed thirty years ago. A few objects that at one time or another had been doubtfully accepted are now moved to the category of open clusters, or of spheroidal galaxies. Half a dozen have been added as a result of close examination with the large telescopes. Miss Sawyer at the Harvard and David Dunlap Observatories, Baade at the Mount Wilson Observatory, Trumpler and Mayall at the Lick Observatory, Lampland and Tombaugh at the Lowell Observatory, and Shapley, Paraskevopoulos, and Mrs. Seyfert at the Harvard Observatory have contributed to the

cleaning and extension of my 1930 list of ninety-three objects. A few specific comments on the distribution of clusters are in order:

1. The plot in Figure 1, and the discussions that immediately follow, do not include the globular clusters that are associated with other galaxies, which will be considered in a later section.

2. Two of the accepted clusters, NGC 2419 and NGC 1841, are very distant and may be either "intergalactic tramps" or more or less free members of the local group of galaxies, rather than physical members of our galactic system. And of course similar independence could be claimed for other clusters (that are now not distant) until we are able to throw doubt on their independence through full information about radial velocities and cross motions, and about the overall dynamics of the galactic system.

3. Trumpler has suggested that the well-known open cluster, Messier 67, can also be classed as a globular cluster on the basis of its luminosity-color array, and perhaps a few other galactic clusters could also be similarly included in the globular category. The thought is provocative and useful, but such an assignment of Messier 67 seems to be a stretching of the definition further than would be generally acceptable.

4. Dreyer's catalogue of 1888 (the familiar NGC) contains ninety-six of the now accepted ninety-seven globular clusters, although many of them were not identified at the time of discovery or time of cataloguing as globular clusters. The one exception, I.C. 4499, appeared in the later Index Catalogue, after its discovery on Harvard plates in 1901 by Delisle Stewart.

5. In striking contrast to the asymmetrical distribution of globular clusters, the galactic clusters are distributed not too unevenly in all longitudes, and almost exclusively in low galactic latitudes.

The question naturally arises: Are there many undiscovered globular clusters? It is possible that a few may be added through further exploration of some of the faint spheroidal objects that are already listed in the NGC and the Index Catalogues. A few may be added in low latitudes in the general vicinity of the galactic nucleus, through the use of red-sensitive plates and the large-scale reflectors; for if the obscuring nebulosity is not too heavy, some of the objects lying beyond the galactic center may be revealed. It is generally agreed that in all probability many clusters lie in or behind the heavy absorption that affects the Milky Way throughout the whole fourth quadrant of galactic longitude. Edmondson has predicted from his consideration of distances and motions that a hundred globular clusters, members of our galactic system, remain out of the records.

The three most important deductions from Figure 1 are (1) the essentially even division of the system of globular clusters by the galactic circle; (2) the apparent concentration of the globular clusters

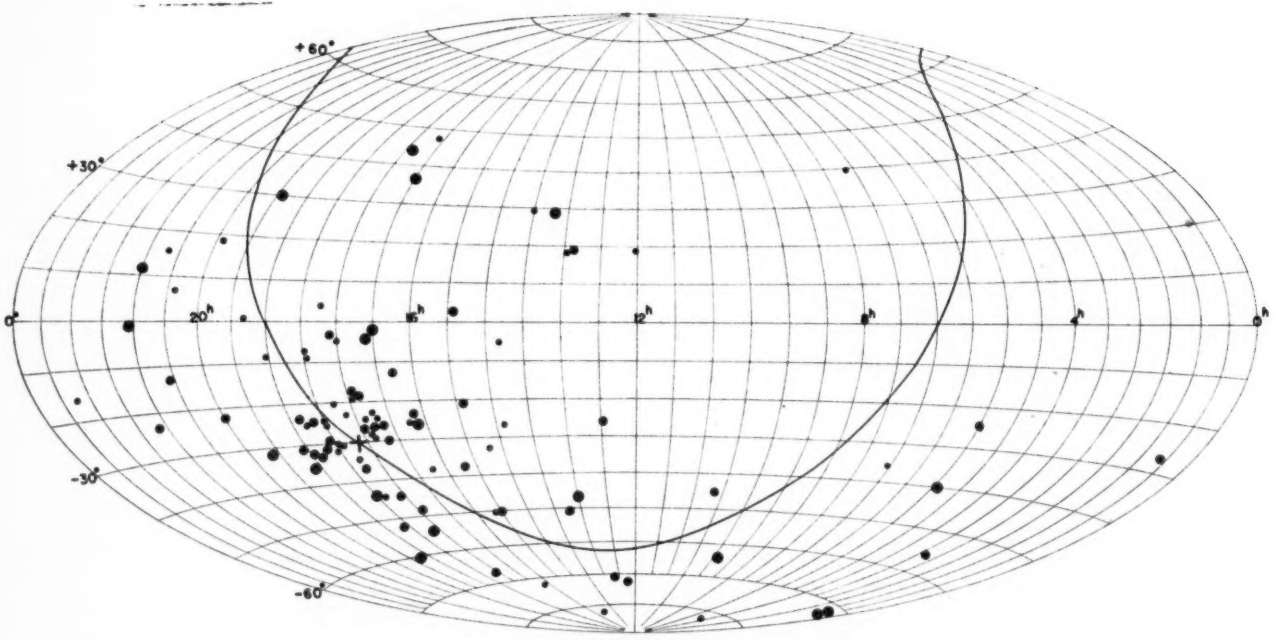

FIGURE 1

Distribution of globular clusters on the surface of the sky. (Aitoff equal area projection.) The galactic circle is superposed on the equatorial coordinate system. It is crossed at $17^h\,30^m$, $-30°$, which is approximately the center of the system of clusters and of the Galaxy.

toward the galactic plane; and (3) the centering of the system around galactic longitude 325°, galactic latitude 0°. The even division into two hemispheres and the concentration toward the center are strong evidences that the clusters are a structural part of our galaxy and that they have long been associated with the great system of Milky Way stars, probably from the dim days of galactic origin. The location of the center of the cluster system in the dense star clouds of the southern Milky Way draws special attention to that region, so heavily disturbed with dark clouds of light-dimming material.

It was of course this concentration toward longitude 325° that led in 1917 to the hypothesis (which is no longer considered hypothesis) that the sun is far from the center of our stellar system. The galactocentric theory of the stellar system replaced rather rapidly the generally-held heliocentric assumption. But the fact that the sun and naked-eye stars were off-center was not nearly so difficult to accept as was the scale of galactic dimensions that was introduced through the measurement of the distances of these globular sub-systems. Although we later found some fairly good evidences in the distribution of stars of special types (*e.g.*, the novae) to support the hypothesis that the center of the galaxy is in the Sagittarius direction, and still later the analysis of stellar motions and the measures of cosmic static confirmed it convincingly, it was the distribution of the globular star clusters that led the way and has produced the most effective argument for the sun's highly eccentric location in the Milky Way. This result is perhaps the most important of the four major contributions of the clusters to cosmogony.

With hesitation we first placed the sun half-way toward the edge of the wheel-shaped galactic system; but later it has become necessary to recognize that the sun and naked-eye stars are really far outside the main body of our spiral galaxy. There are, to be sure, traces of the galactic system stretching at least twenty or thirty thousand light years farther out in the anti-center direction: our Harvard variable star work in the second quadrant (of galactic longitude) reveals this anti-center extension. But contrary to appearances, these outer regions where we are, and beyond, are of relatively low density and sparse population. Studies by Seares and Mowbray have emphasized this fact.

It is difficult to adjust our superficial view of the Milky Way to the clear evidence that we are peripheral, especially when we look at the heavy star clouds in Cygnus, at right angles to the direction to the Milky Way center. It is quite certain, however, that if the heavy obscuration did not completely conceal such a great part of the sky in the central regions (Ophiuchus, Scorpio, Sagittarius), and if it did not also dim considerably almost all the stars visible in those directions, the difference in brightness between Sagittarius and Cygnus would be convincingly conspicuous.

Unless our galactic system is more complicated than a typical Sb

or Sc galaxy, it now seems clear that the heavy spiral arrangement among the giant stars is, for our system, ten thousand light-years or more inside our orbit about the galactic center. A relatively light spiral structure may still prevail in this outer region.

III. Measuring the Distances with Cepheids

Without the Cepheid variable—that most powerful of all tools for measuring large stellar distances—we would still be ignorant concerning the spatial arrangement of the system of globular clusters that centers on the galactic nucleus. The zero point of the period-luminosity relation for Cepheid variables is derived, as is well known, wholly from the apparent magnitudes, proper motions, and radial velocities of Cepheid variables in the galactic system, and the shape of the period-luminosity curve is derived basically from the Magellanic Clouds. But the variable stars of the globular clusters, which will be discussed in a later section, enter the establishment of the important fainter end of the period-luminosity curve, for in half a dozen of the globular clusters are a few long-period Cepheids that provide a definite tie-up between the abundant cluster-type Cepheids and the classical Cepheids of the Clouds and of our Milky Way.

Although the Cepheid variable, through the unambiguous relation of luminosity to length of period, is historically and practically the key to the measurement of the distances of globular clusters, the bright invariable stars of the clusters have also become valuable criteria of distance, now that their luminosities have been calibrated by way of the Cepheid variables. It is a surprising and useful characteristic of globular clusters that, except in a few of sparse population, the maximum brightness of the giant stars is closely the same from one cluster to another.

The property of an upper limit on luminosity, first used extensively to get the distances of those globular clusters that were without Cepheid variable stars, has later been used for deeper explorations of the metagalaxy. Whereas the brightest individual stars in globular clusters nearly always fall between absolute photographic magnitudes —1 and —2, the absolute photographic magnitudes of the brightest supergiants in the spiral galaxies attain absolute photographic magnitudes between —5 and —7. Once we know these absolute magnitudes and measure the apparent magnitudes, we compute distances in parsecs from the familiar relation $M = m + 5 - 5 \log D$.

We can go a step further in the use of luminosity as a criterion of distance. We can simply use the integrated apparent magnitude of a whole globular cluster as a measure of distance, after we have deduced the average integrated absolute magnitude of some of the nearer clusters for which the distances are determined through the use of their Cepheid variable stars. In other words, the fainter a globular cluster, the greater its distance. Similarly, the integrated apparent magnitudes of external galaxies can be estimated and used, with a recognized risk,

to get the distances of extremely remote galaxies. The risk lies in the considerable dispersion in the integrated absolute magnitudes of galaxies and our necessity of using mean values.

We must constantly remember, of course, that the luminosity methods are good only when the space through which we work is essentially transparent, or when, if the object under measurement is seen through interstellar clouds of gas and dust, we know the actual amount of the absorption.

We can illustrate the photometric method with the northern globular cluster Messier 3, which is rich in variable stars. It lies in a region well populated with distant external galaxies, and therefore we can safely assume that the correction for space absorption is small or perhaps entirely negligible. The cluster variables have a median apparent photographic magnitude of 15.43, and since the median absolute magnitude of such stars is currently accepted as zero, we can take 15.43 as the distance modulus, $m_v - M_v = 5 (\log D - 1)$, where the distance D is expressed in parsecs. The brightest non-variable stars in the cluster have the apparent magnitude $m_b = 13.9$, and therefore an absolute photographic magnitude of $M_b = m_b - (m_v - M_v) = 13.9 - 15.4 = -1.5$.

Similarly, the integrated apparent magnitude of all the stars in Messier 3 is 7.2 photographic (about 6.5 visual), and therefore the integrated photographic absolute magnitude of the cluster is $7.2 - 15.4 = -8.2$.

To use these values, —1.5 and —8.2, for the absolute magnitudes of the individual brightest stars and of the total cluster, respectively, to get the distances of other globular clusters that are devoid of measured variable stars, we must make the brave assumption of similarity among the clusters. We assume Messier 3 and the other clusters are alike in population. Or, if we admit the probability of dissimilarity, we must accept, as a part of the uncertainty in the determined distances, the error contributed from the spread of the absolute magnitudes. Recognizing these limitations, however, we find that the application of the principle is simple. We measure the apparent magnitudes of the brighter stars, or the apparent magnitude of the total light of the cluster whose distance we seek, and without further measurement use the adopted mean absolute magnitude in computing the distance from the modulus. The dispersion in the absolute magnitudes of the brighter stars seems to be relatively small, in comparison with the dispersion in the total magnitudes of clusters.

For a considerable number of the most remote globular clusters of our galactic system, the total magnitude method must still be used for estimating distances in the absence of a photometry of the individual bright stars or variables. The recognized spread in absolute luminosities naturally gives a relatively low weight to the distances thus derived.

Another criterion of distance is the angular diameter of a globular

cluster. (See Section VI.) Here again we find a considerable spread around the mean linear value; but the combined use of the apparent diameter and the total apparent magnitude can certainly yield a rough quantitative value of the distance of an object that is otherwise immeasurable.

Although in my earlier work the distances, uncorrected for space absorption, were given for all the recognized globular clusters, and although later workers, in particular, Baade and Stebbins and his colleagues, have attempted for clusters in low galactic latitude to correct the preliminary distances by making allowance for space absorption, we can as yet accept safely only the distances of the high-latitude clusters. In Table 1 is a condensed presentation of the distances of globular clusters in latitudes higher than $\pm 20°$.[2] Thirty-one objects are included, about one-third of all those known. One of them is Omega Centauri, in galactic latitude —15°. It is included because of its intrinsic interest, as one of our most gigantic globular clusters, and also because we believe a fair estimate can be made of the amount of space absorption in its direction.

TABLE 1

NGC	Messier	Galactic Longitude	Galactic Latitude	Apparent Magnitude	Distance (kiloparsecs)	Absolute Magnitude
104	(47 Tuc)	272°	—45°	(4.5)	7.6	—10.2
288		157	—88	8.96	14.5	— 6.8
362		268	—47	8.0	10.0	— 7.3
1261		237	—51.5	9.5	22	— 7.2
1851		212	—34.5	7.72	14	— 8.1
2419		148	+26	11.51	56.2	— 7.7
4147		226	+79	11.01	20.0	— 5.5
4590	68	269	+36	9.12	13.5	— 6.8
5024	53	305	+79	8.68	20.2	— 7.8
5053		310	+78	10.9	17.4	— 5.3
5139	(ω Cen)	277	+15	(4.7:)	6.8	—10:
5272	3	8	+78	7.21	12.2	— 8.2
5466		8	+72.5	10.39	17.0	— 5.8
5634		310	+48.5	10.8	32	— 6.7
5694		299	+29	10.87:	33.1	— 7.1:
5897		312	+29	9.61	13.8	— 6.5
5904	5	332	+46	7.04	10.1	— 8.0
6205	13	27	+40	6.78	9.5	— 8.1
6218	12	344	+25	7.95	8.3	— 7.3
6229		40	+40	10.26	30	— 7.1
6254	10	343	+22	7.64	8.3	— 7.6
6341	92	36	+35	7.30	10.3	— 7.8
6752		303	—26.5	7.2:	5.8	— 7.4:
6809	55	336	—25	7.08	5.8	— 7.7
6864	75	347	—27	9.50	42	— 8.9:
6934		20	—20	10.01	18	— 7.0
6981	72	3	—34	10.24	16.6	— 6.6
7006		32	—21	11.45	44	— 7.3
7078	15	33	—28	7.33	11.5	— 8.3
7089	2	21	—36	7.30	13.8	— 8.5
7492		22	—64	12.33	25.1	— 4.7

Half a dozen other recognized globular clusters with galactic lati-

[2] *Harv. Repr.*, 257, 1944.

tudes greater than 20° are known, but as yet the photometric investigations of their stars, or the estimates of the probable space absorptions that must be allowed for, are not sufficiently accurate to warrant their inclusion.

The total photographic magnitudes of Table 1 are taken from an investigation by Christie,[3] who got around the major difficulties of estimating the magnitudes of such difficult diffuse objects by the employment of a Schraffierkassette which provided him with uniform out-of-focus images that permitted accurate measurement.

From the distances and apparent magnitudes of the globular clusters we derive at once the total absolute magnitudes plotted in Figure 2. We note that there are two gigantic clusters, Omega Centauri

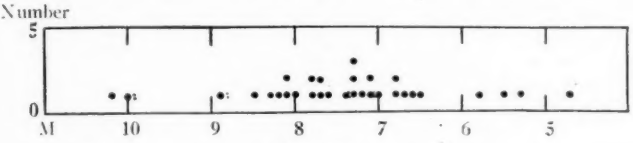

FIGURE 2
Dispersion in absolute magnitude.

and 47 Tucanae, with absolute magnitudes in the vicinity of —10, that is, more than a million times the luminosity of the sun. On the other hand four of the clusters have absolute magnitudes about one hundred times fainter, with values less than —6. These "giant poor" or loose globular clusters are, in the total light of their thousands of stars, equal only to a single supergiant star like the brightest in a Magellanic Cloud or a spiral galaxy.

The median photographic absolute magnitude of all 31 clusters is —7.3. The two nearest clusters in this list, M55 and NGC 6752, are of average luminosity, as are the two most remote, NGC 2419 and NGC 7006, with absolute magnitudes of —7.4, —7.7, —7.7, —7.3, respectively. These values suggest that the dependence of apparent brightness on distance has not spuriously affected our measures of total absolute luminosity, even though the two giants, Omega Centuri and 47 Tucanae, are also among the nearest. There may be equally gigantic globular clusters far behind the obscuring dust clouds.

IV. Spectral Types and Integrated Colors

Although, as we shall see later, it is possible to get and make important use of the colors of individual stars in globular clusters, we have been unable, because of their faintness and strong concentrations to get spectral classes in more than a few of the brightest objects. F. G. Pease did some good pioneer work in this field. D. M. Popper has summarized the earlier observations on the spectra of individual stars[4] and has added spectra for 14 and 21 bright stars in Messier 3

[3] *Mt. Wilson Contr.*, 620, 1940.
[4] *Ap. J.*, **105**, 204-211, 1947.

and Messier 13, respectively. He finds the spectra of these giant stars mostly of types G5 to K0, with peculiarly weak cyanogen absorption. The types are in proper agreement with the colors measured by me in the early photometry of these two clusters.

Integrated spectra of many of the clusters have been recorded by Miss Cannon in the Henry Draper Catalogue. These composite spectra are of limited usefulness and significance. They vary from A5 to K, with an average not far from F8 or G0. Such average spectral classes are what would be expected from a conglomerate of stellar types that range from B to M. By far the most careful examination of the spectra of a large number of globular clusters is that carried out by N. U. Mayall in the course of his study of the radial velocities.[5] He finds an average of F7.6, and none later than G5. There is no close dependence of color on type.

The integrated color indices, and in particular, the color excesses, as measured photoelectrically by Stebbins and Whitford,[6] are of much higher significance than the integrated spectra, because they can lead directly and quantitatively to estimates of the intervening absorption. (The color excess of a star is the excess of redness over that normal in clear space for the star's spectral class.) This color work gives us the possibility of obtaining rough distances of the otherwise hopeless clusters embedded in the obscuration along the Milky Way. Stebbins and Whitford have derived colors for 68 globular clusters and find several color-excesses in low latitudes larger than half a magnitude. The corresponding interstellar absorptions are in excess of two magnitudes. As would be expected from the blotched appearance of the southern Milky Way, the absorption shown by the photoelectric measures is spotty. No uniform correction, as a function of galactic latitude or longitude, is possible. If in addition to spottiness the relation between measured color-excess and total dimming is not the same from one part of the sky to another, then the derived distances are quite unreliable in low latitude no matter how many Cepheids or bright stars are precisely measured.

The most remote globular cluster for which the evidence is complete is the isolated NGC 2419 mentioned earlier, for which Baade derives a distance of 180,000 light-years.

It may be that the globular clusters nearest the earth are some of those that are heavily veiled in the Milky Way, rather than Messier 55 and Omega Centauri, or other conspicuous systems of the southern high-latitude sky. Greenstein's[7] study of colors in heavily obscured Messier 4 indicates a correction of nearly three magnitudes for the interstellar absorption, with the result that this neighbor of Antares is

[5] *Lick Obs. Contr.*, Series II, 15, 1946.
[6] *Mt. Wilson Contr.*, 547, 1936.
[7] *Ap. J.*, **90**, 387, 1939.

probably our nearest globular cluster, with a distance of about 6,000 light-years.

V. Star Population of a New Kind

Much attention has been paid in the past two or three years to the question of types of stellar population. It is of interest to note briefly the contribution of globular clusters to the population problem, and to observe how slowly sometimes we grasp the significance of dissonant observational material.

Table 2 was published in 1915.[8] It was such a surprising result, this

TABLE 2

Color Luminosity Array in Messier 13

Limits of Photovisual Magnitude	Color-Class b0 to b5	b5 to a0	a0 to a5	a5 to f0	f0 to f5	f5 to g0	g0 to g5	g5 to k0	k0 to k5	k5 to m0	All Colors
11.80-.99											
12.00-.19								1	3	2	6
.20-.39									1	1	2
.40-.59								3	2		5
.60-.79				1	1		1	2			5
.80-.99							4	2			6
13.00-.19	1					1	8	3			13
.20-.39						1	4	2	1		8
.40-.59						1	6	1			8
.60-.79						2	3	1		1	7
.80-.99		3		2	6	14	6	2			33
14.00-.19					1	9	3	2			15
.20-.39			1			10	13	4			28
.40-.59		1	1	7	3	24	16	4			56
.60-.79			6	2	1	6	12	1	1		29
.80-.99		5	3		2	5	8	2			25
15.00-.19		24	9	3	3	19	10	2			70
.20-.39	10	21	7	5	12	28	15				98
.40-.59	4	11	6	4	11	11	5	1	1		54
.60-.79	1	5	3	3	10	4	1				27
.80-.99											
Total	16	70	36	27	50	135	115	33	9	4	495

evidence that the giant red stars were much brighter than the giant blue stars in the globular cluster Messier 13, that attention was called at once to the contrast between this color-luminosity diagram and the one that prevailed for stars around the sun, and for the open clusters like the Hyades. It was noted that the difference must have a bearing on the evolution of stars; but just what that bearing may be was as obscure then as it is now.

To test the generality of the Messier 13 color-magnitude array, careful studies were made of three other bright globular clusters, Messier 3, Messier 5, and Messier 15. Later Messier 68 was examined, and a less thorough study made of Messier 4, Messier 9, and Messier 14. In all of them the same phenomenon appeared.[9] For all of them Russell's "reversed seven" diagram, applicable to stars of the solar neighborhood, is distorted, so far as the giant stars are concerned. Every globu-

[8] *Mt. Wilson Contr.*, 116, 51, 1915.

[9] There is a brief summary in *Mt. Wilson Commun.*, 34, 1916.

lar cluster tested shows the absolute luminosity brightening with increasing color.

Curiously enough, the anomaly attracted little attention from observers or interpreters, even after Lundmark and others had noted the structural and color similarities of globular clusters, spheroidal galaxies, and the nuclei of spirals.[10] A dozen years after its discovery, ten Bruggencate monographed the star clusters in a treatise that still remains of high value as a presentation of methods. In a thorough examination of the color-luminosity diagram, he rediscussed my material and again called attention to the two types of population. Meanwhile Trumpler had proposed his classification of galactic clusters and showed from his extensive studies of the spectra in these open systems that the color-luminosity arrays were not like those of the globular clusters. Additional work was done on the colors of giant stars in globular clusters by Nassau and Hynek (Messier 12), Greenstein (Messier 4), and others, with the standard result.

Quite independently of any consideration of the population type in globular clusters, Oort discussed in 1926 the properties of galactic stars of high velocity,[11] and noted that such stars could be differentiated in several characteristics from stars in general. The globular clusters of course were known to have high velocities, but they were not directly associated with high velocity galactic stars, except possibly with the galactic cluster-type Cepheids. Several of us pointed out, as mentioned above, the similarity of globular clusters with the nuclei of spirals and with the spheroidal galaxies. It was generally assumed that the stellar content was similar, and by analogy similar to the content of the nucleus of our own galactic system which the Harvard and Mount Wilson workers had shown is also very rich in cluster-type Cepheids.

Such is briefly the history of the color-luminosity anomaly, but it took the dramatic resolution of the nucleus and the companions of the Andromeda Nebula by Baade with the 100-inch reflector,[12] and his calling attention to velocity differences as well as the differing color-magnitude arrays, to make astronomers "population sensitive."

It may turn out that we are over optimistic in assigning star assemblages to only two distinct populations. The data on velocities are somewhat ambiguous, suggesting perhaps several population types, or perhaps a continuum with maxima. The luminosity discriminant appears, however, to be clear and positive. But if the two population concept plays only the same part in studies of stellar evolution as the two star streams of Kapteyn played in analysis of galactic structure, it will have been sufficiently fruitful. The two populations are of course intermingled. All spiral galaxies are composite. In 1916 Seares had observed that the nuclei of spirals are yellowish, the spiral arms bluish;

[10] *E.g.*, the globular-cluster nucleus of NGC 7793, a Sd spiral; Shapley and Mohr, *Harv. Bull.*, 907, 1938; Lundmark, *Pub. A.S.P.*, **42**, 23, 1930.

[11] *Groningen Publ.*, **40**, 1926.

[12] *Mt. Wilson Contr.*, 696, 1944.

and that is what an external observer would find in comparing our galactic nucleus with the Pleiades, or with the star fields in Carina. Since the total amount of light emitted by the arms of a spiral is much less than the light from the nucleus and the main body of the galaxy on which the spires are superposed,[13] we are probably correct in saying that most stars are in population II. From present evidence the stars commonly assigned to the first population are extremely rare in globular clusters and spheroidal galaxies or totally absent.

In Table 3 the relationship of color to absolute luminosity is shown

TABLE 3

	Messier 22*			Messier 68†	
Color Class	Mean Pv. Magnitude	Number of Stars	Color Class	Mean Pv. Magnitude	Number of Stars
b	14.39	40	b	.....	...
a	14.30	173	a	15.49	4
f	13.88	261	f	15.00	15
g	12.99	102	g	13.97	26
k	12.03	27	k	12.79	10
m	11.17	20	m	.....	...
		Total 623			Total 55

*From *Harvard Bulletin* 874, 1930. †From *Mt. Wilson Contr.* 175, 1920.

for the globular clusters Messier 22 and 68. The color classes correspond to the like-lettered spectral class — b the bluest, m the reddest. Why the cluster stars behave this way, and why most of the giant stars of the solar neighborhood behave otherwise, is of course yet to be worked out.

VI. The Diameters of Clusters

How thick is the earth's atmosphere and how large is a globular cluster are questions with the same type of indefinite answer. Both the atmosphere and the clusters taper off into undetectable thinness. If the escaping atoms of air and the "evaporating" stars are included in the definitions, then the thickness and diameter are indeed immeasurably large. To get useful values, we must measure something other than the complete extent.

The diameters, both angular and linear, of globular clusters can be defined in various ways that permit us to obtain relative values with some certainty. The extent of the recognizable images on photographic plates leads to the simplest definition, and it turns out to be more valuable than one based on individual star counts, since in the outer parts confusion with the field stars arises. The recognizable extent of the photographic image naturally depends also on the population of the foreground and background star fields, also on the focal ratio of the photographic camera and the length of exposure. The extent measured on the photographs depends also on the method of measurement, for example, whether by visual estimates or densitometer tracings.

[13] Shapley, H., *Galaxies*, pp. 29, 170, 1943.

TABLE 4

NGC	Galactic Latitude	Absolute Magnitude	Class	Diameter—Apparent—Measured	Diameter—Apparent—Estimated	Diameter—Linear (parsecs)	Distance (kpc)
104	—45°	—10.2	III	53′.6	23′	118	7.6
288	—88	— 6.8	X	13.1	10.0	55	14.5
362	—47	— 7.3	III	17.7	5.3	51	10.0
1261	—51.5	— 7.2	II	....	2.0	..	22
1851	—34.5	— 8.1	II	11.5	5.3	47	14
2419	+26	— 7.7	VII	5.1	1.7	84	56.2
4147	+79	— 5.5	III	2.8	1.7	16	20.0
4590	+36	— 6.8	X	....	2.9	..	13.5
5024	+79	— 7.8	V	15.8	3.3	93	20.2
5053	+78	— 5.3	XI	....	3.5	..	17.4
5139	+15	—10:	VIII	65.4	23	129	6.8
5272	+78	— 8.2	VI	22.1	9.8	78	12.2
5466	+72.5	— 5.8	XII	....	5.0	..	17.0
5634	+48.5	— 6.7	IV	6.8	1.3	62	32
5694	+29	— 7.1:	VII	....	....	..	33.1
5897	+29	— 6.5	XI	13.1	7.3	53	13.8
5904	+46	— 8.0	V	25.0	12.7	74	10.1
6205	+40	— 8.1	V	18.1	10.0	49	9.5
6218	+25	— 7.3	IX	21.0	9.3	51	8.3
6229	+40	— 7.1	VII:	5.3	1.2	48	30
6254	+22	— 7.6	VII	21.5	8.2	52	8.3
6341	+35	— 7.8	IV	(14)*	8.3	42	10.3
6752	—26.5	— 7.4:	VI	41.9	13.3	70	5.8
6809	—25	— 7.7	XI	28.7	10.0	48	5.8
6864	—27	— 8.9:	I	8.7	1.9	105	42
6934	—20	— 7.0	VIII	....	1.5	..	18
6981	—34	— 6.6	IX	8.0	2.0	38	16.9
7006	—21	— 7.3	I	....	1.1	..	44
7078	—28	— 8.3	IV	18.1	7.4	60	11.5
7089	—36	— 8.5	II	16.9	8.2	68	13.8
7492	—64	— 4.7	XII	....	3.3	..	25.1

(*) Nassau, J. J., *Ap. J.*, **87**, 366, (1938).

In Table 4 the densitometric measures made on Harvard photographs by Shapley and Sayer[14] are given for twenty-three of the thirty-one globular clusters of Table 1 for which the distances have been most reliably determined.[15] The angular diameters as estimated from simple plate inspection are also given.[16] They well illustrate the advantage of the densitometer in tracing the fainter outlying parts of the clusters. The average ratio is:

$$\text{Densitometer/visual} = 2.81.$$

In the last two columns of the table are the linear diameters (computed from the currently adopted distances and the measured angular diameters in a preceding column), and the distances, which have been adjusted for the space absorption that is indicated by the background population of external galaxies.

In Figure 3, the measured angular diameters of the images in minutes of arc are plotted against the logarithm of the distance. The correlation is moderately good, and in consequence the dimensions of

[14] *Harv. Repr.*, 116, 1935.
[15] *Harv. Repr.*, 257, 1944.
[16] "Star Clusters," *Harv. Mono.*, No. 2, pp. 224, 226, 1930.

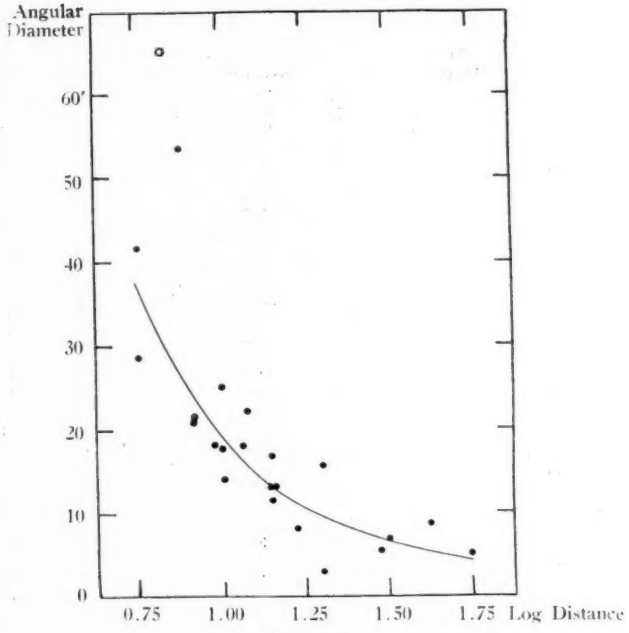

FIGURE 3
Dependence of angular diameter on distance for 23 globular clusters.

the photographic images, carefully measured, can be used as a fair indicator of distance. This angular diameter criterion is not very dependable, however, in the low latitudes where interstellar absorption prevails, because the measurable apparent diameter there appears to be diminished by the absorbing material, in much the same degree as the apparent brightness is diminished. This unfortunate circumstance, which prevents what would be an easy and fairly accurate measurement of the distance of all globular clusters whatever the interstellar foreground, probably arises from the fact that the fainter stars in globular clusters are progressively less concentrated to the center; the measurable diameter of a given cluster is therefore different for different magnitudes, and when only the brightest stars shine through, the angular diameter is measured spuriously small.

The linear diameters of the twenty-three globular clusters naturally show no certain correlation with the distances. They are plotted against absolute magnitudes in Figure 4. Naturally the interdependence of linear size and total mass (and luminosity) is expected. The big cluster, Omega Centauri, is included in Table 4 and as an open circle in Figure 4, although its low latitude of $+15°$ may still leave

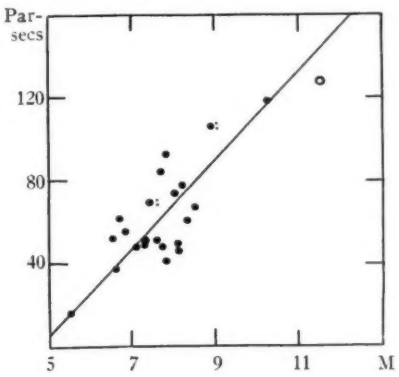

FIGURE 4
Size and brightness for 23 globular clusters.

some uncertainty with regard to its distance and therefore with regard to its linear diameter.

The most striking result from the densitometric measures is the demonstration of much variation in the real sizes of globular clusters. The diversity is also found when other definitions and measures of the dimensions are employed. Whatever the method used for measurement of the photographic image of a globular cluster, it does not reach out to all stars that are real members. Cluster-type Cepheids of the same median magnitude as those in the thick of the cluster are occasionally found at more than the measured radius.

Special attention should be called to the dimensions of the giant globular clusters 47 Tucanae (NGC 104) and Omega Centauri. Their luminosities are comparable with the luminosities of the dwarf galaxies, such as IC 1613; and the linear diameters are comparable with the linear diameters of some of the spheroidal galaxies as estimated on photographic plates. But, when surveyed with the densitometer, the average spheroidal galaxy is much larger than the globular clusters. The dimensions of NGC 205, one of the faint companions to the Andromeda Nebula, are 15′.8 by 9′.1, according to Baade,[17] and the diameters of its distant pair of faint companions, NGC 147 and NGC 185, are 14′.1 and 14′.5, respectively. With distances of about 250 kpc, the linear diameters are therefore about ten times that of the largest globular clusters.

The various definitions of diameter, useful for measuring globular clusters, have been surveyed by Mowbray.[18] The distance from center to that circle beyond which lies one-half the total light of the cluster has been proposed by Hertzsprung and by others as the definition of

[17] *Mt. Wilson Contr.*, 696 and 697, 1944.
[18] *Lick Obs. Contr.*, Series II, 14, 1946.

an "effective" radius, but in practice, the contours of luminosity are difficult to determine without introducing errors arising from various photographic factors. The distance at which the surface brightness is one-half the central surface brightness, or some other fraction of the central surface brightness, is used by Mowbray, who has measured these "core" dimensions for sixty-four clusters on plates made with the Crossley reflector at the Lick Observatory. The correlation with the diameters estimated directly on the plates, he finds, is not good. This is doubtless attributable in part to differences in degree of central concentration of the bright stars.

VII. Classifying Globular Clusters

The observed central concentrations of globular clusters are both structural and an effect of distance. Nearby clusters naturally appear on the photographic plates to be more open. As a convenience in describing this combined effect of distance and structure, I have set up twelve classes. Class I is the most concentrated; Class XII the loosest in apparent organization. The thirty-one clusters of Table 4, assembled in order of class into three groups, show the following means:

Classes	Number	Mean Angular Diameter	Mean Absolute Magnitude	Mean Distance
I-IV	11	16.7	—7.7	20.7 kpc
V-VIII	11	24.5	—8.0	19.1
IX-XII	9	16.8	—6.4	14.7

There is much dispersion about these average values, but it appears that concentration class is not certainly correlated with distance, luminosity, or angular diameter, except for the most open third of the clusters which average to be nearer and fainter. The data show, in fact, that the classification is based chiefly on real structural variety and not much on distance, for if the clusters are grouped in order of distance we have the means:

Number	6	5	5	5	5	5
Distance	7.1	10.3	13.5	16.7	23.5	41.5
Class	VII	IV	VI	X	VI	IV

VIII. The Variable Stars

Two recent papers on globular clusters by Dr. Helen B. Sawyer[19] have presented the general literature of the clusters and a catalogue of their variable stars in such convenient detail that little additional need be said about the subject in this summary. Reference has already been made to the epochal work of Professor Solon I. Bailey, who for many years used the abundant photographic material of the Harvard plates. Not only did he find more of the variables in globular clusters than anyone else, but at the termination of his work he had also determined the periods of more than half of all Cepheids that had been

[19] *David Dunlap Observatory Publ.*, 4, 1939; 20, 1947.

identified in globular clusters. His classification of the light-curves into sub-classes a, b, and c is generally accepted.

Several investigators have examined the growing material on the frequency distribution of the periods of cluster variables. Among others Oosterhoff has presented the distribution for five of the clusters richest in variables (ω Cen, M 3, 5, 15, 53) and Miss Sawyer for these and eight others.[20] They find significant differences in the relative frequencies of the various sub-classes. It appears that sub-class a and sub-class b cannot be very clearly separated, although the latter has longer periods and on the average a somewhat smaller range. The following tabulation from Oosterhoff[21] is of interest in showing that among the five variable-rich clusters, Messier 3 and Messier 5 have relatively few sub-class c stars, and the average length of period for their variables is 15% less than for the other clusters:

	——c-type——		—a- and b-type—	
	Number	Mean period	Number	Mean period
ω Centauri	57	$0^d.37$	77	$0^d.65$
Messier 15	28	.38	31	.65
Messier 53	15	.36	17	.62
Messier 5	13	.32	63	.54
Messier 3	27	.32	124	.55

Messier 4 is similar to these two. Miss Sawyer's analysis suggests three distinct types of frequency-of-period curves.

As more material becomes available, and the magnitudes and perhaps the colors are more accurately measured, something fairly significant may come out of the studies of these variable stars with periods less than a day. For example, Schwarzschild's studies of the variable stars in Messier 3 with the Wyeth reflector at Oak Ridge have indicated that a cluster star of a certain luminosity and color can scarcely escape variability.[22] His work foreshadows the possibility (pointed out by Baade) that the absence of cluster-type Cepheids in many globular clusters may be due simply to the absence of stars of the appropriate candle-power and color. Kuiper has suggested[23] that the hydrogen content of the stars, and of the clusters as a whole, may be involved in the striking richness of some clusters and poverty of others.

Of a total of nearly thirteen hundred variable stars detected in the sixty-two globular clusters that have been more or less seriously examined, more than 90% are cluster-type variables. The type of a variable in a globular cluster can be rather safely estimated by the apparent magnitude and observed range of variation, even when the period and light curve have not been determined. There are some thirty classical Cepheids, and a few irregular variables, in the globular clusters among the stars brighter than the typical cluster variable. In 47 Tucanae are

[20] *Ibid.*, No. 11, 1944.
[21] *The Observatory*, **62**, 106, 1939.
[22] *Harv. Circ.*, 437, 1940.
[23] *Harv. Bull.*, 903, 1936.

three long-period variables—strange objects because of the similarities in maximum magnitude, amplitude, and period, and their extraordinarily high absolute luminosity (—3.3 pg.):

Number	Maximum	Amplitude	Period
			d
1	11.3	4.7	212.40
2	11.5	3.8	202.84
3	11.4	4.7	192.34

The classical Cepheids in globular clusters show a peculiarity in period frequency. The maximum frequency is not between four and five days as in the galactic system (near the sun), and not around four days as in the Large Magellanic Cloud, or between two and three days as in the main body of the Small Magellanic Cloud. The distribution, however, is not unprecedented. It is much like that of the Cepheids in the central core of the Small Magellanic Cloud and in the nucleus of our own galaxy,[24] where five day periods are scarce and periods of ten to twenty days and longer are most common.

In the study of the magnitudes of the Cepheids in globular clusters no serious deviations from the period-luminosity relation have been found. And the light curves of the cluster-type Cepheids in the globular clusters are comparable in detail with those of the galactic system.

The space occupied by globular clusters extends to great distances from the galactic plane, even though they are definitely concentrated toward the galactic nucleus. It is the space throughout which we are also finding isolated cluster-type Cepheids.[25] It has been natural to speculate that the cluster-type Cepheids at large distances from the galactic plane are "escape stars" from globular clusters, but unless the presently accepted time scale is far too short, it seems impossible to trace their origin to that source. Many very distant cluster-type Cepheids are in the hemisphere that is essentially free from globular clusters. It is more probable that the remote cluster-type Cepheids of the "galactic haze" are escapes from the massive nucleus of the galaxy, if from any concentrated stellar system, for the galactic nucleus, with a stellar population like that of the globular clusters and the spheroidal galaxies, is known to be exceedingly rich in cluster-type Cepheids.

Various investigators, chiefly Martin[26] and Miss Wright,[27] have studied the changes in the periods of cluster-type Cepheids. The actual changes in period length are small or quite undetectable; but the number of oscillations that have occurred in these quickly pulsating stars, since the earliest series of photographs were made, is so large that changes of a small fraction of a second can be demonstrated. The regularity with which some of them come to maximum light long ago in-

[24] *Harv. Repr.*, 214, 1940, and 241, 1942.
[25] *Harv. Repr.*, 173, 1939.
[26] *Leiden Ann.*, **17**, Part 2, 1938, for ω Centauri.
[27] *Harv. Bull.*, 915, 1941, for NGC 2401.

spired Barnard to suggest that the cluster-type variable could well serve as a sidereal clock.

One interesting practical use of the cluster-type Cepheid, in addition to its most important function of serving as a measure of distance, was demonstrated many years ago through the measures in both blue and yellow light of the times of maxima of variables in the globular cluster Messier 5.[28] If we take the maximum (or the precisely determined median magnitude) for a star in a distant cluster as a signal, radiating in all wave-lengths, then by measuring the time of arrival of that signal (the light-curve maximum or median) on photographic plates, we can determine, if we use blue and yellow light separately, the relative speed through the space separating star cluster and observer. As shown by Figure 5, there is no essential delay or advance of yellow light over

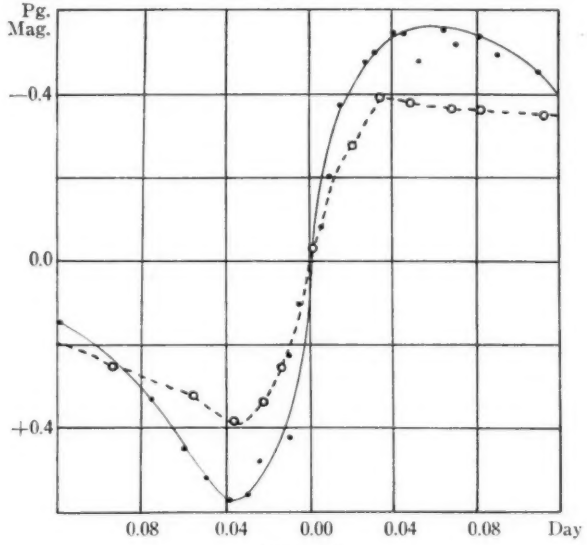

FIGURE 5

Test of velocity of light. Composite photographic (full line) and photovisual magnitude curves for 11 variables in Messier 5, showing by coincidence of median and maximum magnitudes the equal speed of blue and yellow light. (From *Harv. Mono.*, **2**, 111, 1930.)

blue light. The speeds are the same. The experiment would not be decisive for a single star because observed simultaneity might conceal some large difference that is a multiple of the period length. But since no difference is found even when many variables of different period lengths are simultaneously measured in blue and yellow light, that uncertainty is removed. (See Figure 5.)

[28] *Harv. Mono.*, 2, Chap. VIII, 1930.

The revised distance of Messier 5 is 33,000 light-years. The mean error of the determination of the mean maxima is about one minute. Therefore the accuracy of the measured equality in speed of blue and yellow light is one part in fifteen billion. This may be one of the most precisely determined negative results in all astronomy.

IX. Motion and Structure

At the very beginning of the study of the stars in globular clusters two tasks were undertaken that even now, after half a century, have paid off poorly. They are the detection and measurement of proper motions, and the discovery of the laws of star density and luminosity distribution in globular clusters.

The failure of the proper-motion work to yield positive results has kept us from knowing much of the true space motions of clusters and of the internal dynamics of the systems. We now know, of course, that the great distances (previously unsuspected) thwarted the hopeful early proper-motion studies by Barnard, Küstner, Ludendorff, and others. Nevertheless, some of the early positional work, and certainly the early photographs, will soon begin to give useful data on cross motions. Van Maanen's work on the Mount Wilson plates was a good start. If the cross motions are, as is likely, comparable in size with the radial motions, an interval of a century or two between first and last plates will be necessary to record proper motions for the majority of the globular clusters. The relatively nearby systems, Messier 4 and Messier 22, may give the earliest positive results. Messier 13, for which the star positions have been carefully measured, is perhaps five times as difficult.

The word globular naturally suggests sphericity, but most of the cluster images are measurably non-circular, which implies that the clusters are oblate or prolate spheroids. Among the conspicuously elliptical images are those of Messier 19 (nearly twice as long as wide), Messier 22, Messier 62 (irregular in form), and Omega Centuari in which the long axis is outlined not only by the general population of stars but also by the distribution of its variables. Presumably these globular clusters are somewhat flattened by preferential rotation about an axis, or by some other dynamical agency.

The distribution of stars in a globular cluster remains an incompletely solved problem for several reasons. As yet not enough careful attention has been paid by workers with large long-focus telescopes to the observational requirements. The Eberhard effect and other difficulties arising from the crowding of star images to the centers of the typical globular clusters make the photographic study of stellar distribution in the nuclei difficult and deceptive. The fragmentary nature of the data on the colors and spectra of individual stars blocks the work on individual types. The great distances of clusters makes it practically impossible to photograph stars of absolute magnitudes fainter than +2.0, except in a few of the nearest systems.

As a consequence of these limitations, especially the last-named, we do not know the character of the general luminosity curve (frequency of absolute magnitudes of all spectra together). We can, therefore, only guess at the total masses. We know that the very brightest giants are more concentrated to the center than stars of magnitude zero and fainter, but our information on the number and distribution of faint stars in globular clusters is as yet so scanty that theoretical studies of structure are seriously hampered. The analyses of stellar distribution in the past are based on probably but one or two per cent, or even less, of the component stars, and a minute fraction of the mass. Hertzsprung, Schilt, Nabokov, and especially F. S. Hogg have attacked the problem of structure by way of the light distribution in the integrated photographic images. An attack with the modern photoelectric photometers would make this approach more valuable, but better knowledge of the general luminosity curves is still essential.

We can go little further at present than to say that throughout some parts of some clusters the number of the giant stars decreases inversely as the fourth power of the distance from the center. (A third power law and a fifth power law can also be fitted in some instances.) This means, of course, a very high concentration. E. C. Pickering, Von Zeipel, Stratton, Eddington, Jeans, ten Bruggencate, and others have examined the distribution, some of them attacking the problem from the standpoint of the kinetic theory of gases.

The general luminosity curves of the giant stars, for the half dozen globular clusters for which sufficient observations have been made (mostly from my Mount Wilson measures), show one striking phenomenon in common that is doubtless of importance in the population-structure of globular clusters. The singularity is a hump on the rising branch of the hopelessly incomplete general luminosity curve—a surplussage of stars near absolute magnitude zero. This is the magnitude of the cluster-type Cepheids. No good explanation has yet been offered for the existence of such a preferred luminosity. It has been found, in different degrees, however, too many times to be discounted as a statistical fluctuation.

Notwithstanding the unsatisfactory state at the present time of the problem of density distribution, we should record the conviction that here is one of the most important fields for further observational and theoretical work. Its solution is perhaps also the solution of the dynamical nature of the spheroidal galaxies and the nuclei of spirals. It naturally touches the problem of the cosmic time scale and the evolution of galaxies. Some current work on the general luminosity curves, in the outer parts of the brighter and more open globular clusters in the southern hemisphere, is under way at the Harvard Observatory. It should help to answer questions of total masses and populations. Work on radial velocities with small-dispersion spectrographs should give at

least some glimpses of the interior dynamics and guide further theoretical investigations.

Estimates of the total number of stars in globular clusters range from 50,000 to 50,000,000 and more. For some of the "giant-poor" clusters the populations may be much less—only a few thousand. If we should, on the basis of the color-luminosity array, include in the globular category some open systems like Messier 67, the minimum populations can be reduced to a few hundred stars; but such an extension of the definition of course contributes little to the analysis of the inner structure and population of systems like Messier 13.

Returning to the observations of motions of globular clusters as units and of motions within them, we find in one respect a much less desperate situation than with proper motions and density laws. Thanks to the Doppler effect, we can measure the line-of-sight motions with fast stellar spectrographs, even though the fuzzy and faint nature of the target makes high precision impossible. Dr. V. M. Slipher thirty years ago did pioneer work in this field, as in several others where spectroscopic skill was involved. In 1918 he gave preliminary radial motions of ten globular clusters. The velocities were large compared with those for stars, but smaller than his contemporaneous values for spiral nebulae.

The fact that the dispersion of velocities of giant stars in Messier 13 (and probably in other clusters) is but a few kilometers a second, is the provisional but none-the-less very important contribution by Popper, who derived this result as a byproduct of his work at the McDonald Observatory on the spectral classes of the individual stars.[29]

The whole material on the radial motions of globular clusters has been summarized by Dr. N. U. Mayall, who has himself, with the aid of the Lick Observatory spectrographs contributed more than anyone else to our knowledge of globular cluster motions.[30] He has reported also on the over-all system of clusters that can be deduced from the radial velocities, when used in connection with our information on distances and positions. Mayall's summary touches on the earlier work of many others—Slipher, Sanford, Pease, Stromberg, Moore, Baade, Humason, and Edmondson.

Although the velocities are not yet known for about one-half of the globular clusters of the galactic system because they are too far south for northern observers, Mayall finds from his analysis of the available material that the clusters form an approximately spherical system, probably in relatively slow rotation around the galactic nucleus, and perhaps somewhat flattened at the poles of rotation. The rotational speed is apparently about thirty per cent that of the sun and surrounding stars, and in consequence the globular clusters appear to be drifting back toward the solar antapex with a speed of about two hundred kilometers

[29] *Ap. J.*, **105**, 204-211, 1947.
[30] *Lick Obs. Contr.*, Series II, 15, 1946.

a second. Participating in this slower rotation, and therefore in the preferentially high velocities with respect to the sun, are the galactic system's cluster-type variables (at least many of them) and the high velocity stars discussed by Oort in 1926 and more recently by Miczaika.[31] Both the high and low velocity stars have different average motion from that of the external galaxies; and everywhere there are exceptions to the general tendencies. It is all pretty complicated and the motions and relationships badly need the healthy clarification of further observation.

X. Miscellaneous Items

1. *Globular clusters in other galaxies.* For many years we have been puzzled by objects in the Andromeda Nebula that we should like to call globular clusters. Hubble and Baade, with the Mount Wilson reflectors, have recorded more than two hundred of these objects, which appear along the borders of the spiral arms or quite outside the most obvious spiral structure.[32;33] They have been studied photometrically at Harvard (unpublished) and at the Case Institute of Technology by Seyfert and Nassau. The distance of three-quarters of a million light-years prohibits the clear resolution and definitive classification of these circular, centrally-concentrated hazy objects. And their average absolute brightness is a magnitude or more fainter than the average for the globular clusters of our galaxy, if the present estimate of the distance of the Andromeda Nebula, based chiefly on Hubble's magnitudes of the long-period Cepheids and Novae, is approximately correct. If we should try to match the average absolute magnitudes of the globular clusters of the two systems, it would be necessary to increase the distance of the Andromeda Nebula to more than a million light years.

In the Magellanic Clouds many of the globular clusters can be resolved (Figure 6). There is among them a considerable spread in luminosity, as in the galactic system. As yet no variable stars have been found in the Magellanic Cloud clusters. On the average their absolute luminosities lie between those of the clusters in our galaxy and those of the Andromeda Nebula.

Two globular clusters have been found in the peculiar sparse spheroidal galaxy in Fornax,[34] and probable globular clusters have been provisionally identified in other members of the local group of galaxies.

2. *Relationship to open clusters.* In an earlier section the similarity in total brightness of the most gigantic globular clusters (Omega Centauri, 47 Tucanae) to the dwarf spheroidal galaxies, and to the nuclei of some spirals, has been mentioned. There may be a genetic relationship between such globular clusters and the smaller galaxies. But a relationship with the open clusters in the Milky Way is now considered

[31] *A.N.*, **270**, 249-275, 1940.
[32] *Mt. Wilson Contr.*, 452, 1932.
[33] *Ap. J.*, **102**, 377, 1945.
[34] *Pub. A. S. P.*, **51**, 42, 1939.

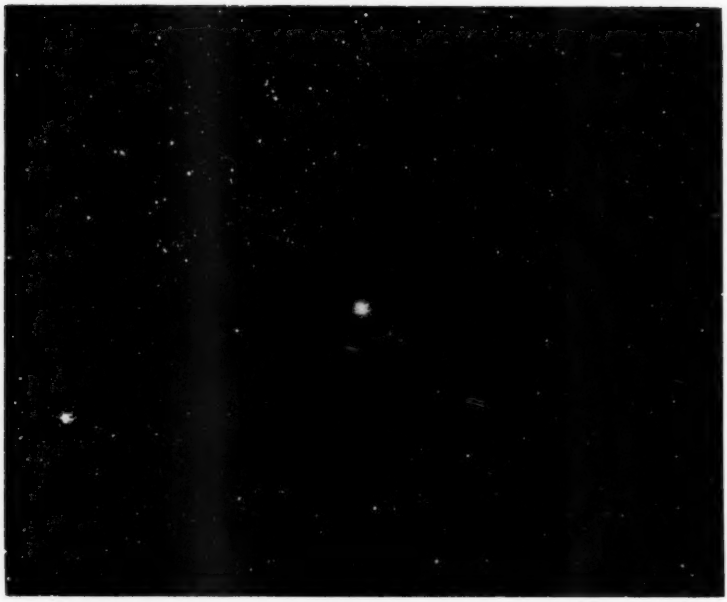

FIGURE 6
NGC 1783—a globular cluster in the Large Magellanic Cloud.

unlikely. There is, to be sure, some overlapping in sky position, and in the spreads of linear dimensions, and total luminosities; but the differences in color-luminosity arrays, variable star susceptibility, space velocities, galactic concentration, total population, and maximum luminosities of individual stars indicate clearly that open clusters are not structurally or genetically related closely to the globular clusters.

3. *The unsolved problems.* To one who has worked long with the globular clusters it seems as if practically nothing has yet been satisfactorily solved. The problems ahead are numerous, interesting, significant, and some of them for the present impossible. Among the most important we might list:

a. Radial velocities for the still unmeasured southern globular clusters.

b. Application of precise photoelectric photometry to various cluster problems (colors, distribution of median magnitudes, integrated magnitudes and colors, etc.).

c. The general luminosity curves in the outer portions of the bright clusters down to absolute magnitude +5, or fainter.

d. Period variation for both cluster variables and the infrequent classical Cepheids.

e. Theoretical studies of the "evaporation" of stars from the boundaries of the clusters.

f. The density and luminosity decrements as functions of distance from the center.

g. Theory of the structure of clusters and of their evolutionary trends.

h. The spectra and radial velocities of individual stars in globular clusters.

i. Further study of the clusters, globular and otherwise, in external galaxies.

In the next two decades the new telescopic power that is becoming available should make noteworthy advances with many of these problems.

FEBRUARY, 1949.

Lights in the Moon

By C. STANLEY OGILVY

"Till clomb above the eastern bar
The hornéd Moon, with one bright star
Within the nether tip."[1]

The usual reaction of the astronomer who encounters these famous lines from Coleridge is a smile and perhaps a charitable shrug. Yet the fact remains that in Coleridge's time the question of "lights in the moon" was still an open one; and even today we may find a background of plausible fact behind what seems at first to be only poetic fantasy.

There are three obvious interpretations of the anomalous star between the points of the crescent. (1) Coleridge simply made a blunder, through plain ignorance of astronomy. (2) He meant "almost between." (3) He was employing poetic license; anything could happen on the "spectral sea" being described by the Ancient Mariner.

John Livingston Lowes, whose "Road to Xanadu" is based on a most exhaustive study of sources, suggests that none of these three explanations is the correct one. Far from being an astronomical ignoramus, Coleridge was an ardent reader of the *Philosophical Transactions of the Royal Society of London*, the outstanding learned periodical of the day,[2] as well as any other scientific literature he could lay his hands on. Lowes finds evidence in Coleridge's personal notebook that he had had occasion to refer to Vol. 5 of the *Transactions* on another matter. At the top of a page of that volume, where "it leaps to catch the attention of the most careless reader,"[3] is the statement that "in November 1668, a Star appear'd below the Body of the Moon within the Horns of it." This information was supplied by Cotton Mather, from Boston, where it was supposed to have been observed. It could not have actually

been *below* the bright part of the moon, since the horns never point downward after dark; but the original reference from which Mather took his data says: "In November following [1668] appeared a Star between the horns of the moon in the midst."[4] Mather's introduction of the spurious "below" is typical of the inaccuracies of early scientific reporting which bedevil the seeker of precise historical data.

We come now to much more authoritative sources, world-famous astronomers whose opinions Coleridge must surely be forgiven for having credited. In 1794, just three years before the "Ancient Mariner" was written, Nevil Maskelyne wrote in the *Transactions* "An Account of an Appearance of Light, like a Star, seen in the Dark Part of the Moon, on Friday the 7th of March, 1794."[5] This account contains letters from two independent and widely separated observers, both of whom submitted sketches (in substantial agreement with each other), and one of whom—one William Wilkins by name—ascertained the time as about 8 P.M. by consulting a neighbor shortly after he had made the observation. This matter of the time is of considerable importance, as will be seen presently.

Wilkins wrote "I was, as it were, riveted to the spot where I stood, during the time it continued [about 5 minutes] and took every method I could imagine to convince myself that it was not an error of sight." He was something of an amateur astronomer, and had a reflecting telescope at home. He "had determined to return and use it on this occasion; for it was so fixed, I had scarcely a doubt but its appearance would continue; but almost at the same instant, and whilst I was looking, it totally disappeared." And in another letter, after further questioning by Maskelyne, Wilkins answered, "I am very certain of this spot appearing *within* the circumference of the moon's circle."

The other observer, Thomas Stretton, saw what he described as "a light like a star, and as large as a middle-sized star, but not so bright [!], in the dark part of the moon." Stretton was not sure of the time, but the evidence (based on his later estimate of the then position of the moon) brought it closer to 7 than to 8 o'clock.

We move swiftly to the denouement: on the same night as the observed phenomenon, a few minutes before 7 o'clock, Aldebaran was occulted by the moon, in a position quite close to where the "star in the moon" occurred. Maskelyne was of course aware of this, and admitted it to be "a singular coincidence of circumstance," yet stoutly defended the evidence of the 8 o'clock observation. He discounted the time element of the other observation, and was in fact easily able to persuade Stretton that he might have been in error. We cannot so lightly dismiss the coincidence of the occultation. The moon was about 5 days old—at precisely the phase when the optical illusion that the bright part of the disc is of larger radius than the dark part is most pronounced. Even an experienced observer is surprised at the tiny appearance of the dark disc which sometimes (very faintly at this phase) can

be seen illuminated by earthshine. This conspiracy of nature would of course place a star about to be occulted well within the circumference of the apparent disc. The sudden and complete disappearance as reported by Wilkins fits exactly the description of an occultation. (Stretton lost the star by going indoors.) Finally, if the star seemed fainter than it should have (Aldebaran's magnitude is 1.06), that is easily explained by the proximity of the bright moon.

Maskelyne offers no explanation of the event. He remarks only that it was probably "of the same nature with that of the light seen of late years in the dark part of the moon by our ingenious and indefatigable astronomer, Dr. Herschel, with his powerful telescopes, and formerly by the celebrated Dominic Cassini."

This leads us to Sir William Herschel's account,[6] which is most specific. He speaks with confidence of volcanos. This under the date April 19, 1787, $10^h\ 36^m$ sidereal time: "I perceive three volcanos in different places of the dark part of the new moon. Two of them are either already nearly extinct, or otherwise in a state of going to break out; which perhaps may be decided next lunation. The third shows an actual eruption of fire, or luminous matter. I measured the distance of the crater from the northern limb of the moon and found it 3′ 57″.3." No guesswork here. And now we have another curious coincidence. The careful sketch which Wilkins made in his notebook after observing the phenomenon of seven years later shows the bright spot, or star, about 4′ from the northern limb!

"April 20, 1787, $10^h\ 2^m$ sidereal time. The volcano burns with greater violence than last night. I believe its diameter cannot be less than 3″. . ." He goes on to compare this with the one he had seen four years previously which, "though much brighter than that which is now burning, was not nearly so large. . . Seen in the telescope, it resembled a star of the fourth magnitude as it appears to the natural eye." Presumably, then, none of Herschel's lights were visible to the naked eye, if it required a telescope to bring them up to an apparent magnitude of 4.

Herschel subsequently revised his opinion, feeling by no means so sure of his volcanos in later years. Clerke states that he was "completely, though temporarily, deceived into the belief that he had witnessed volcanic outbursts," and on the same page attributes them to "the reflection of earthlight at a particular angle from certain bright summits."[7] Modern astronomy texts seldom mention the matter, but Arago devoted a chapter[8] to it, discussing Maskelyne's and Herschel's reports in a mildly reproving tone, much as if he were shaking a finger at these two distinguished gentlemen for having allowed themselves to be so deluded.

Haas, in the May, 1947, issue of this monthly, describes lights observed on the moon, but not of a durable charcater, and only specks even with a telescope.[9]

Is there, then, any possible source of bright light in the dark of the moon which might be mistaken for a star? One occurs immediately to the modern astronomer, knowledge of which was not available in Coleridge's day: a wandering asteroid might, by great coincidence, line itself up between the earth and the moon for a brief interval. Hermes, for example, can come within 220,000 miles of the earth—20,000 miles nearer than the moon. But when Hermes was 485,000 miles away in 1938, its magnitude, according to Duncan,[10] was 8, and its velocity was 5° an hour. Thus at its nearest possible distance Hermes might just be visible as a 6th magnitude object, but could not possibly be classified as a "bright star." It would in all probability move at an apparent velocity so high that it would cross the entire face of the moon in a matter of a few minutes. Moreover, it would, if it were in line with the crescent moon, be crescent itself, which would further greatly reduce its magnitude.

It is not inconceivable that at some time in the past another asteroid, large enough to appear as a bright star, may have found its way temporarily into the required position between earth and moon. But the possibility is exceedingly remote; and the behavior of Maskelyne's star does not, of course, confirm such a hypothesis for that particular instance.

If we still insist, then, on a realistic explanation of what the Ancient Mariner was supposed to have seen, we must fall back on the theory that, although a star was not actually between the horns of the moon, it seemed to be. Since it was a morning moon (it "clomb above the eastern bar,") the star must have been seen after emergence, and there was no danger that it would suddenly do a disappearing act, further to confound the already overwrought Mariner.

Perhaps the only remaining alternative is the answer given recently by an undergraduate to the familiar examination question, "Comment on Coleridge's line, 'The hornéd moon with one bright star within the nether tip'." The student wrote, "The hornéd moon refers to the crescent moon and the bright star refers to a speck in Coleridge's eye. If the star had been beyond the moon it would have been occulted, and if it had been nearer than the moon it would have burned Coleridge up." With this sage observation we might well bring our discussion to a close.

References

[1] Samuel Taylor Coleridge, "The Rime of the Ancient Mariner," lines 209-211.

[2] John Livingston Lowes, "The Road to Xanadu," Houghton Mifflin 1927, p. 180.

[3] *Ibid*, p. 41.

[4] Josselyn, "An Account of Two Voyages to New England," 1675, as quoted in "The Road to Xanadu," p. 477.

[5] *Philosophical Transactions of the Royal Society of London*, 1794, Vol. 84, pp. 429-440.

[6] *Ibid*, 1787, Vol. 77, pp. 229-231.

[7] Agnes M. Clerke, "History of Astronomy During the Nineteenth Century," London, 1908, p. 266.

[8] Francois Arago, POPULAR ASTRONOMY, translated into English, 1885, Vol. 2, Book XXI, Ch. 31.

[9] Walter H. Haas, "A Report on Searches for Possible Lunar Meteoric Phenomena, POPULAR ASTRONOMY, Vol. 55, p. 266.

[10] John C. Duncan, "Astronomy," Harper, 4th Ed., 1946, p. 275.

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The Observing Record for the First Ten Years of the McDonald Observatory

By DOROTHY HINDS and GERARD P. KUIPER

With the completion of the calendar year 1948 it is of interest to compile the statistics of the observing done with the 82-inch telescope of the McDonald Observatory. The percentages of sunshine given in the chart published in *McDonald Observatory Contribution* Number 1 give 75 per cent for the Davis Mountain region of Texas. However, these sunshine data are only approximate and, moreover, nighttime conditions are often different from those prevailing in daytime. For instance, during the summer months cumulus clouds form above the mountains which cause much of the precipitation recorded during these months, while frequently the nights are clear or partly clear.

The statistics on the observing hours have been kept since the first day of operation of the 82-inch telescope, March 1, 1939. Since that date each observer has recorded the CST of the beginning and the end of his nightly observations as well as the attachment used. It is possible, therefore, to subdivide the total number of observing hours by month or by year as well as by attachment. This has been done in Table 1, which is largely self-explanatory; all figures have been rounded off to the nearest full hour though the original records showed quarters and halves which were used in the additions.

It is seen that the seasonal variations of the percentages of observing are remarkably small. However, as a result of the longer winter nights, the actual number of observing hours per month is greatest during that season. It is also seen that all but two months, January and April, have had records above 80 per cent while poor months, 50 per cent or below, may also occur at any season. The comparatively uniform distribution of observing weather is a great aid in programs requiring observations distributed over the whole sky. Occasional daytime observations, primarily in the infrared, have not been added in the present compilation.

The annual totals show some correlation with total rainfall. The poorest observing year, 1941, was exceptionally wet while the best years, 1945 and 1947, had below-average rainfall. The average monthly rainfall does not correlate closely with average observing percentages,

TABLE 1

	1939	1940	1941	1942	1943	1944	1945	1946	1947	1948	Totals	Aver-age	Pos-sible	Average %	Best %	Worst %	Average Rainfall (Inches)
January	....	222	224	264	219	252	278	168	207	256	2089	232	362	64	77	46	0.70
February	....	195	173	171	209	206	230	238	250	160	1832	204	311	65	81	51	0.35
March	189	169	171	242	221	257	229	199	241	202	2120	212	319	67	81	53	0.37
April	165	190	161	190	197	142	194	202	198	193	1833	183	277	66	73	51	0.81
May	140	156	108	196	154	211	185	212	215	219	1796	180	262	69	84	41	1.81
June	161	122	152	191	168	174	201	165	204	198	1736	174	240	72	85	51	2.86
July	112	201	150	241	176	213	184	172	240	104	1793	179	274	65	88	38	3.27
August	166	176	143	91	250	170	240	212	125	208	1780	178	277	64	91	33	3.16
September	258	231	82	208	211	178	234	168	233	231	2034	204	294	69	88	28	3.21
October	220	205	127	179	224	256	196	186	282	180	2053	205	334	62	84	38	2.16
November	139	168	200	242	233	119	318	210	262	252	2202	220	347	64	91	34	0.43
December	280	228	200	257	166	250	207	170	298	219	2274	228	370	62	81	45	0.88
Totals	1830	2262	1949	2474	2427	2427	2696	2301	2756	2421	23,544	2399	3667[2]	65.4			
	61%[1]	62%	53%	67%	66%	66%	74%	63%	75%	66%	65%	65%	100%				
Spectrographs	1648	1854	1839	2296	1936	1981	2143	1874	2587	1478	19,637 (84%)						
Direct Photography	161	408	110	152	230	138	197	177	....	239	1811 (7%)						
Micrometer	21	....	....	26	261	308	356	250	....	382	1604 (7%)						
Photometer	....	....	....	....	....	....	....	....	170	322	491 (2%)						
Rainfall (Inches)	....	....	36.2	20.6	17.0	22.5	15.0	19.4	15.5	13.9	....	20.0					

[1] Based on 10 months.
[2] Arrived at by using time for each day of the year ½ hour after civil twilight to ½ hour before civil dawn.

largely because the summer rains fall primarily in daytime and not at night. It is also noted that five-sixths of the time has been used in spectrographic research and only one-sixth in direct photography, micrometer, and photometer together.

The percentages in Table 1 are quite sensitive to the somewhat arbitrary definition of the length of a clear night. This should be borne in mind when comparisons are made with similar records for other observatories. The definition adopted here (see footnote 2 in Table 1) is believed to correspond closely to the actual observing practice at the McDonald Observatory, so that a perfect month would yield 100 per cent and not 90 or 110 per cent.

Russell W. Porter

1871-1949

By O. S. MARSHALL

Dr. Russell Williams Porter died the evening of February 22, 1949. He had passed his 77th birthday the 13th of the preceding December. He worked a few hours in the morning on a nearly finished six-inch achromatic objective, after which he felt his end drawing nigh. His going was as a certain man expressed a desire for himself over a hundred years ago, "My body with my charge lay down and cease at once to work and live."

From his boyhood, throughout his career, Dr. Porter's star was one of increasing magnitude. In two particulars he has made a permanent place for his memory in Astronomy's Hall of Fame: His work in connection with the Palomar Observatory and its 200-inch telescope, and his creation of the Amateur Telescope Makers Movement. (See POPULAR ASTRONOMY for March, 1923.)

To all who came to know Dr. Porter even casually, he was Russell. Russell was born in Springfield, Vermont, of sound English ancestry. His parents were Swedenborgians in faith. His father, always bearing the appearance of a polished gentleman, followed a mildly varied career: inventor, manufacturer of children's baby carriages, druggist, photographer in the Daguerreotype days, and, finally banker. Russell was the youngest of three children, the oldest of whom was a girl. He began his glass-working quite young. His father discovered some broken window panes in the gable of their barn, and traced the origin of this damage to Russell. Collecting a few pebbles he invited his young son, Russell, to a position in front of the barn and handing the pebbles to Russell asked him to throw them at his face. "That just about broke my heart," said Russell when narrating the episode.

Russell's environment and heredity entered into his blood-stream. Even so, his career was his own orbit. He was definitely of the wanderlust pattern, intellectually and terrestrially. He could become a Robin-

son Grusoe with the same ease that he became an Associate in Optics and Instrumental Design. He early put a high value upon technical education and training, therefore he graduated from M. I. T. in the courses of Architecture and of Art. There he studied under the able French Architect-Engineer, Desire Despradelles. In addition to executing a large drawing of a mammoth structural tower-monument 1500

MR. PORTER AS A STUDENT AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

feet in height, which his instructor conceived as placed in Chicago's dismantled Columbian Exposition grounds—but was not realized—Russell won the Gold Medal Award in a nation-wide contest in Architectural Design.

After several adventures within the Arctic Circle, the last being as Second in Command of the Baldwin-Ziegler North-Polar Expedition, under the command of Anthony Fiala, which came to a rather inglorious consummation after three seasons in the frozen North in 1905, Russell chose Port Clyde for his next adventures. At Port Clyde, Maine, with a partner-friend architect they constructed several bungalow cottages for tourists. Two important things happened here which affected Russell's future career: He met and married Miss Alice Belle Marshall on Thanksgiving day in 1907. Whatever credit or fame now attaches to Russell is justly shared by his incomparable life companion, as all will affirm who have known this matchless couple. The second important thing is that which finally climaxed in what already has been indicated, The Amateur Telescope Movement.

One of Russell's duties on that North-Polar expedition was recording star-time with the transit during the long night vigil. From that he acquired a thirst for astronomy, and, the twin-thirst to own a telescope. His experiences in the frozen north had not enriched him financially.

Soon after settling in Port Clyde he chanced upon an article in POPULAR ASTRONOMY written by a coffee merchant that told about working glass by heat and abrasion. The novelty of this article, especially its authorship—he had forgotten the man's name—aroused him emotionally: "If such a fellow can do it, I can!" It was a favorite expression with Russell: "Your wits and your two hands will do it!" Then and there dawned Russell's real day. From his first parabolic mirror of 4 inches diameter, he ended with two of 16 inches diameter: one a parabolic mirror, the other an optical flat. These two mirrors are now incorporated in his Indoor Observatory at Stellafane in Springfield, Vermont.

Russell began writing for POPULAR ASTRONOMY himself. One of these articles was accompanied with several simple sketches, one of which showed a "horse-shoe ring" design for the north-polar bearing of a large astronomical telescope. This appeared in the March, 1918, issue of POPULAR ASTRONOMY. It caught the vigilant eye of Dr. George Ellery Hale who was frequently in Washington, D. C., during the first World War. Russell worked in the Optical division of the Bureau of Standards during the final months of that war, and he and Dr. Hale met one day. The net result of their meeting was Russell's being asked by Dr. Hale in late 1928 to join the new Two Hundred-Inch Telescope project as Associate in Optics and Instrumental Design. It is superfluous to indicate Dr. Hale's many attributes, one of which was his ability to see that in Porter he was getting an extraordinarily gifted and trained man who could readily cope with problems in engineering, architecture, art, surveying—a real Leonardo, as Porter's intimate friend, James Hartness, used facetiously to introduce Russell to some stranger. Russell does not suffer by this comparison. He possessed an uncanny ability to interpret a struggling idea in the mind of another, sketch it on paper for the man to see, who would then exclaim: "That's it exactly—how could you do it!"

Russell's temperament was flexible, resilent. He would not quarrel with circumstances. He worked best, accomplished most under difficulties. He was a rapid worker at anything he undertook. He was adamant against "pilfered credit." He never permitted himself to become irritated—unless when asked to clean the attic or the cellar! That did not mean that he esteemed one person above another however. Simply an irksone task "bored him" and he might even show it in the contour of his lips.

The Astrophysical Observatory on Palomar Mountain did not get off at the first drop of the handkerchief. Dr. Hale was in failing health in the early 1930's, but he lived until the project finally got under way and he wrote a brochure descriptive of the assured enterprise. The telescope mount incorporated the Horse-shoe ring in what Dr. Hale called "the modified yoke type of mount." Dr. Hale died on February 21, 1938. The project naturally suffered to some extent for lack of his

steadying direction. It had proven difficult to bring to a common focus the intellects of a select group of scientist-engineers with any such assurance as that of parabolizing, figuring a 200-inch mirror. In the realignment of the designing staff Russell's position became one of greater value to the project, as is attested by his superb drawings 28 inches by 38 inches, showing the completed Observatory and the Hale Telescope—with "flesh on its bones" before the completion of either Observatory or Telescope. These literal interpretations of the project now hang, suitably framed, in the Astrophysical Laboratory in Pasadena. In addition there is a model of the Palomar Observatory site, showing contours and the three Observatories and several buildings, which Russell made and which also is in the Astrophysical Laboratory mentioned. This model Russell made from his surveys of the 2000 acre plot which contains the Observatory site, when he spent some weeks as a "Robinson Crusoe" on Palomar mountain. The model, 38 inches by 58 inches, shows the Observatory site proper with the 200-inch and the two Schmidt Camera Observatories and the principal buildings already constructed, including the power plant. For anyone who cannot visit Palomar mountain a realistic impression of the site, Observatories, and the Hale Telescope may be had by a visit to the Astrophysical Laboratory in Pasadena.

The second World War compelled suspension of activities on the Palomar Observatory project. Dr. Porter's services, however, were rendered in two significant fields: Making of roof prisms and making sketches for the Naval Department of airplane bombing activities conducted in the Mojave Desert. These sketches were primarily for showing the character of the explosive effects in relation to targets. Some hundreds of sketches were made by Dr. Porter which constituted, as

Courtesy of James Fassero.

Dr. Porter at his Drawing Board at the California Institute of Technology.

he said, his first and only participation in warfare. These will be published in official records of the Naval Department. A serious bottleneck was faced by the War Department in the sudden demand for roof prisms. Dr. Porter at once leaped into this gap by personally training enough amateurs to become expert in this task which required the highest skill in optics. He also wrote a brief treatise on this subject for the use of amateurs. The War Department was much astonished and greatly relieved at the suddenness with which their difficulty was solved.

Strange as it may appear, Russell had one defect: He was "color blind" to poetry. Dr. Hale hoped to cure this defect by sending him a copy of one of his own favorite poems by Shelly. But no: it was only so much intellectual hieroglyphics to Russell. And yet Russell was passionately fond of music—especially Beethoven. Further, Russell set to music for the piano several Esquimau airs which his Arctic memory had stored in his mind.

The sobriquet, Robinson Crusoe, has been indicated in Russell's connection. To the very last he felt the call of solitude and he would occasionally yield to its spell—usually by a week-end trip to the desert where infinite terrestrial and celestial distances would nourish his spirit. From these excursions he would return to civilized ways with a handful of pastel sketches and a new surge for his task. While not specifically a member of the Designing Staff, Russell was in constant demand for suggestion, counsel, endorsement concerning not only the main project and its interests, but from numerous outside sources there came constant demands that taxed his energies.

Russell declined one honor proffered him during his Port Clyde days. A French Scientific Society wished to make him a member of its organization in recognition of his photographing the Foucault knife-edge shadow on a parabolised mirror under inspection.

Russell graduated with the degree of Bachelor of Arts from Norwich University before he entered M. I. T. In June, 1946, Norwich University conferred upon him the degree of Doctor of Science. At the same time Norwich University conferred upon General Dwight David Eisenhower the degree of Doctor of Military Science. Middlebury College had announced its intention to confer upon Russell the degree of Doctor of Science in June, 1949. Several scientific societies abroad had invited Russell to become members therein, but his American duties made impractical his aceptance of these invitations.

Due to his profound interest and abiding faith in the Astrophysical Observatory and the Hale Telescope, together with the indicated works of art he executed, Russell's name is permanently linked with this his culminating life ambition. On one of his desert trips Russell and his companions were discussing the Amateur Telescope Movement. His

companion remarked that this Movement would be a lasting monument to his memory. After a moment's pause, Russell observed:

"That is the only monument I want."

PASADENA, CALIFORNIA, MARCH 15, 1949

The Planets in June, 1949

By RAYMOND H. WILSON, JR.

NOTE: The time employed is Central Standard Time unless otherwise indicated. The phenomena have been chosen and described for the North American continent, and especially for the United States. The basic data have been taken principally from the *American Ephemeris and Nautical Almanac*.

Sun. During all this month the sun will be more than 22 degrees north of the equator. The date of summer solstice, when the sun will stand at its maximum of 23½ degrees north, will occur on June 21 at 12 noon.

Moon. The phases of the moon will occur as follows:

First Quarter	June 3	9 P.M.
Full Moon	10	4 P.M.
Last Quarter	18	6 A.M.
New Moon	26	4 A.M.

The moon will be at perigee on June 7.

An occultation of Antares will be visible from the eastern states and northern middle west states at 8:30 on the evening of June 9.

Evening and Morning Stars. Venus and Saturn will be visible in the early evening sky; Jupiter and Mars in the morning.

Mercury. Since it will be 22 degrees west of the sun on June 28, Mercury may be visible in the eastern dawn for the last ten days of this month.

Venus. Being situated near the Twins, Venus will remain above the western horizon for over an hour after sunset during this month. In a telescope its disc will appear at nearly full phase.

Mars. Rising about an hour ahead of the sun, Mars will be passing just north of Aldebaran in the morning sky. Its similarity in color and magnitude to that star may cause erroneous identification unless special care is taken. On the morning of June 24 the planet will appear about 4 degrees south of the waning moon.

Jupiter. This bright planet will be rising at about 11 P.M., and south at about 3 A.M.

Saturn. June will be the last month this year for favorable evening observation of the ringed planet, which may be seen in the western evening sky situated in the constellation Leo.

Uranus. Since it will pass conjunction with the sun on June 22, Uranus will be practically unobservable this month. However, its position on June 6, just a degree southeast of Venus, might serve to identify it on that date.

Neptune. Neptune will be almost stationary at a position 3 degrees southeast of γ Virginis. At 11 P.M. on June 5 the moon will pass less than a degree to the south of it.

Department of Mathematics, Temple University, Philadelphia, Pa.
April 2, 1949.

Asteroid Notes

By HUGH S. RICE

CERES was observed from New York in February, several times, by variable-star observer Edward Oravec and meteor-observer Kenneth Weitzenhoffer. The magnitude of 7 as reported by them corresponds with the predicted magnitude. The planet was picked up with binoculars.

VESTA (asteroid 4) comes to opposition June 13 and may be observed rather conveniently in very small telescopes or even binoculars. At the beginning of our ephemeris, the planet is in western Sagittarius, and during the period of opposition it is moving westward, immersed in the Milky Way in Ophiuchus. About June 20 it passes very close to M 9, a globular star cluster, going north of it. It is very convenient in this case to plot Vesta's apparent path on an atlas like *Norton's Star Atlas,* because the brightness falls sufficiently within the range of the stars of the atlas. In the case of most asteroids such procedure cannot be effected with much efficiency, for the fainter magnitude of the planet does not allow the observer to distinguish (at once) the planet from a star of similar faint magnitude not reproduced on the chart.

Vesta's magnitude at opposition this year is given as 6.0, and this is assumed to be a visual magnitude. Our ephemeris is taken from the annual publication of the American headquarters at the Cincinnati Observatory. The ephemeris of Vesta which is included in a similar book published in Russia, and giving 1949 positions, shows a considerable discrepancy, putting Vesta farther west by about 18^m in R. A. and ½° north in declination, at the beginning of the period; but on June 29 both ephemerides agree essentially. Observers should watch for the slightly pink or orange color often detected in this object. This would appear best in a reflecting telescope; we have witnessed it also in a 5-in. Brashear refractor. The color cannot well be detected in a binocular, even when the object itself is clearly seen; seemingly more light-gathering power is needed. The Russian ephemeris offers a magnitude of 5.9; and under good conditions of observing, it is possible that Vesta may be seen without optical aid.

HEBE (asteroid 6) is at opposition June 16, and is to be found a few degrees north of Vesta. The ephemeris shows that at the beginning of the period it starts in western Serpens Cauda, near Zeta Serpentis, and shortly goes into Ophiuchus. Curiously enough, this planet also passes by a globular star cluster, M 14, about the same day, June 20, as Vesta's close approach to M 9; but Hebe goes south of the cluster. The magnitude of Hebe is given as 8.8 and hence the asteroid can be reached by high-power binoculars or a small telescope.

ASTEROID EPHEMERIDES

For 0^h U.T. Equinox 1950

	4 VESTA			6 HEBE	
1949	α	δ	1949	α	δ
	h m	° ′		h m	° ′
May 20	17 58.3	—17 23	May 20	18 0.9	— 3 37
28	17 49.2	—17 36	28	17 55.6	— 3 17
June 5	17 38.1	—17 50	June 5	17 49.0	— 3 10
13	17 26.0	—18 5	13	17 41.5	— 3 16
21	17 13.9	—18 22	21	17 33.5	— 3 35
29	17 2.7	—18 41	29	17 25.6	— 4 6
July 7	16 53.3	—19 2	July 7	17 18.4	— 4 50
15	16 46.6	—19 25	15	17 12.5	— 5 47

Hayden Planetarium, American Museum of Natural History, New York, April 21, 1949.

Occultation Predictions for June, 1949

(Taken from the *Amerian Ephemeris*)

The quantities in the columns *a* and *b* are given for the purpose of making these predictions useful for any place within 200 miles of the point indicated. The procedure is as follows: Subtract the longitude of the point given from the longitude of the place in question; multiply the result in degrees, taking the signs into account, by the quantity under *a* for the star to be observed; similarly, with the latitude, using *b*; apply the sum of the products, with its proper sign, to the Greenwich C.T., and obtain the predicted Greenwich Civil Time for the phenomenon at the place of observation. To obtain Eastern Standard Time it is necessary to subtract five hours; Central Standard Time, six hours, etc.

Date 1949	Star	Mag.	IMMERSION Greenwich C.T.	*a*	*b*	Angle E from N	EMERSION Greenwich C.T.	*a*	*b*	Angle E from N
			h m	m	m	°	h m	m	m	°
Occultations Visible in Longitude +72° 30′, Latitude +42° 30′										
June 2	107 B.Leon	6.3	23 47.4	−1.3	−1.5	117	0 57.3	−0.7	−2.0	312
6	*h* Virg	5.4	23 47.1	−2.2	+1.0	84	0 39.2	−0.2	−1.9	352
10	*a* Scor	1.2	2 39.8	−1.0	−0.3	138	3 48.3	−2.1	+0.2	263
Occultations Visible in Longitude +91° 0′, Latitude +40° 0′										
June 1	λ Canc	5.9	3 9.2	+0.1	−1.6	117	4 3.2	+0.2	−1.3	286
6	*h* Virg	5.4	23 21.0	−0.8	0.0	124	0 28.3	−1.0	−0.4	310
10	*a* Scor	1.2	2 43.4	..	..	193	2 55.0	..	..	213
15	37 Capr	5.8	8 17.9	−1.8	+1.5	56	9 44.2	−2.0	+0.7	247
21	26 B.Arie	6.1	9 1.7	+0.2	+2.5	18	9 51.3	−1.0	+1.3	277
Occultations Visible in Longitude +98° 0′, Latitude +31° 0′										
June 1	λ Canc	5.9	3 26.5	+0.4	−2.0	144	4 13.8	−0.1	−0.8	262
15	37 Capr	5.8	7 51.0	−1.9	+1.6	66	9 20.3	−2.2	+1.3	242
21	26 B.Arie	6.1	8 42.6	+0.3	+2.2	28	9 34.4	−0.5	+1.2	269
22	π Arie	5.4	10 28.3	−0.5	+1.4	80	11 29.0	−0.2	+2.3	215
Occultations Visible in Longitude +120° 0′, Latitude +36° 0′										
June 1	λ Canc	5.9	3 25.2	+1.3	−4.2	177	3 53.8	−2.1	+0.5	231
7	86 Virg	5.8	7 32.8	−1.0	−2.2	156	8 29.5	−1.1	−1.1	264
22	π Arie	5.4	10 36.4	+0.3	+1.7	49	11 32.8	−0.2	+1.5	253

METEORS AND METEORITES

Meteor Notes from the American Meteor Society

By CHARLES P. OLIVIER, President

Since publishing the annual report for 1948, other observations made during that year have arrived. One set is particularly important, containing several hundred observations made during the last few weeks of the year by Prof. Mohd. A. R. Khan in India. A supplement to the annual report will shortly be prepared to take care of what has recently come.

Most of these Notes will be taken up with a full discussion, which follows, of the great fireball of 1948 June 7, and of its long-enduring train.

Fireball of 1948 June 7

On this date at 8:05 P.M., C.S.T., a splendid fireball, moving north up the Mississippi Valley, was seen by many people and attracted unusual attention

because it left a train which endured probably 10 minutes. My first report was from Tommy Scott, A.M.S. member in Nauvoo, Ala. (10).* I at once informed Science Service and they very kindly wired their cooperating newspapers throughout the region requested. As a result some 70 persons wrote me, mostly from near Memphis and in northern Alabama, but a few from other states. No report was received from Missouri, the state over which computations prove the fireball ended. Many of the 70 persons mentioned wrote a second time or filled out our Bulletin No. 16, going to considerable trouble to furnish full information. On the contrary, one professional and one amateur astronomer, in whose hands I had some reason to believe there were data, both consistently refused to reply to several letters, requesting their cooperation. In the 38 years of the A.M.S., I do not recall that this has previously happened. Due to the above, the solution lacks azimuths from directions which would have considerably improved it.

However, there were favorable features which aided, particularly the fact that the path was almost perpendicular and very near Polaris as seen from Memphis, and also nearly perpendicular from northwestern Alabama. A drawing of the path by Mrs. N. Etchason at Charlestown, Ind. (23), far to the E.N.E., showing the slope, and a careful drawing by Scott (10) well to the S.E., showing it was about 6° long, both greatly aided in finally deciding on the path and the altitudes. As it was still twilight, few stars were visible anywhere so observers had to determine coordinates by estimation, in most cases. However, after several approximations, results were obtained in which I have considerable confidence, though the average deviation for the end height is larger than desirable. The most unexpected feature is the apparent dying out of the fireball itself at about the lower end of the long-enduring train. For such a brilliant object, estimated at —7 magn. from a distance of 200 miles, one would have expected it to be visible to about the 30 or 40 km level, and possibly to have dropped fragments. This object, however, seems to have completely died out at a very high altitude.

We are fortunate in having several drawings and numerous descriptions of the train, which so far as these reports go seems coincident with the whole observed path. (The visible path was almost certainly longer and the beginning height greater than given in our table. This is due to the reports, which give usable altitudes, referring almost without exception to the upper end of the train, not the actual starting point of the meteor. Twilight in fact would prevent this latter from being caught by most persons, for obvious reasons.) The drawings of Scott (10), a well-trained observer, who drew the train on one of our standard meteor maps, shows that it became serpentine, drifted at center to left 2°.9 in 4 minutes, and shortened from 5° to 2°. His full description is quoted: "The train was rather bright at first. Slowly it began to drift and assume a serpentine shape. By the second minute it had somewhat lost this shape. The lower section had begun to spread although it was losing none of its brightness as the rest of the train was. By the third minute the train was showing a definite drift upward. The lower section was still bright and was swinging around in advance of the remaining train. The whole train was enlarging. By the fourth minute much had faded, leaving the advanced lower section. This in turn faded from view about 20 sec. afterwards." Knowing that Scott was about 390 km from the central part of the train, the projected velocity for him was then 300 km/hour.

At Cullman, Ala. (5) W. L. Lowell gave a drawing showing the train somewhat like the figure 3 at 8:08:→E fully confirming (10). If we call the levels from

*Numbers in ( ) refer to stations and/or serial number of observer.

top downward a, b, c, d, e, we find a, c, e about equal and somewhat faster moving than b, d, but all moving parallel and in same direction. At Osceola, Ark., (19) L. Godley said: ". . . appeared to stand perfectly still 2 or 3 minutes . . . a crook developed at lower end . . . a bulge towards the west. . ." From Drakenburg, Ky. (26) Mrs. Geo. Bridges says: ". . . down and to west." At Cordova, Tenn. (30) Dr. W. L. Diggs, who was almost in the vertical plane of the path, gives a drawing showing something like that at (5) but with lower end curved more to the left, *i.e.*, to west. At Rogersville, Ala., (11) Miss C. Patterson sent a good report with a drawing fully confirming (5). From here on the rest of the observers mentioned were in or near Memphis, Tenn.—(44). Mrs. H. A. Jensen gave a diagram confirming (5) and (30). (50) W. M. Gammil gives fine sketches showing that the numbers of zigzags in train had increased before it finally disappeared. (53) Mrs. J. Garrett says ". . . streak glowed brilliantly for several minutes . . . it wafted away as if it were smoke slowly curling from the bottom." (55) Mrs. W. H. Stanley says ". . . the train, at first, seemed to drift a little to the left, then back to the right. As it drifted it seemed to go more to the right and the lower part of it kept drifting more to the right and upwards." (63) A. L. Hall says ". . . white smoke . . . drifting westward until it disappeared." (64) E. F. Beale sends an excellent drawing again confirming (5) and (30) and says it drifted to the west. Some of the other reports have direct or indirect corroborative evidence, but cannot be quoted due to lack of space. Unfortunately all the diagrams were from stations almost in the plane of the fireball's path. A single good one from a station well to the side would have been very valuable. However, (26) furnishes the statement "down and to west," which is clear enough. Summing up the whole, I think that at (10) the proper interpretation of the drawings is not an upward current but the not unusual contracting to the center of such trains along with a southward component. The great preponderence of evidence is for motion to a little south of west, and in five parallel strata as indicated most clearly by (5), (30) and (64) especially. Using the designations given for (5), the best that can be gotten from the data is that a, c, e strata had winds with velocities to W.S.W. of about 300 km/hour, while in b, d winds moved in same direction at about 250 km/hour. The train is described as reddish yellow by several, changing to "smoke-color" or white later. Though it was still twilight, the train had all the usual characteristics of a night train.

The consensus of opinion was that the fireball was orange-red-yellow, or some combination of these colors. Whether the head itself was white and these colors were more properly those of the short tail (not train) immediately behind the head, is open to question. To observers within 100 miles the head showed as a disk, perhaps as much as 15′ in diameter. No explosion was seen and of course no sound heard.

Lastly, we are under great obligations to Science Service and numerous newspapers which printed at length our request for information, and even more to the scores of individuals whose reports made this paper possible. Every report was used in some way or other though lack of space prevents our mentioning the names of most observers. To everyone who aided us we express most sincere thanks and the hope that, should they see another fine meteor, they will send in observations without waiting to be asked. Miss Nancy E. Weber greatly assisted in all the preliminary work on this object.

Date	1948 June 8.09 G.C.T., June 7.59 G.M.T.
Sidereal time at end point	197° 28′
Began over	λ 89° 05′ W, φ 36° 17′ N; height 118 ± 6 km; 6 observers
Ended over	λ 90° 09′ W, φ 37° 00′ N; height 87 ± 27 km; 11 observers
Length of path	88 km
Projected length of path	82 km
Duration	2.50 ± 0.80 sec.; 5 observers
Velocity (as observed; uncertain)	35 km/sec.
Radiant (uncorrected)	a = 346°.5, h = 20°.9; α = 212°, δ = −30½°
Zenith correction (parabolic)	−7°.2
Radiant (corrected)	a = 346°.5, h = 13°.7; α = 214°, δ = −38°

The radiant is A.M.S. No. 2315.

The elements of the parabolic orbit are as follows:

$i = 11°$
$\pi = 297°$
$\Omega = 257°$
$q = 0.89$ A.U.

Train:	
Duration	10± minutes
Height of upper end	118 km
Height of lower end	87 km
Length	88 km
Drift	Towards WSW with velocities 300 to 250 km/h

Note: The computations were carried out to minutes of arc and the results then rounded off to whole degrees.

Flower Observatory of the University of Pennsylvania, Upper Darby, Pa. 1949 April 13.

VARIABLE STARS

Variable Star Notes from the American Association of Variable Star Observers

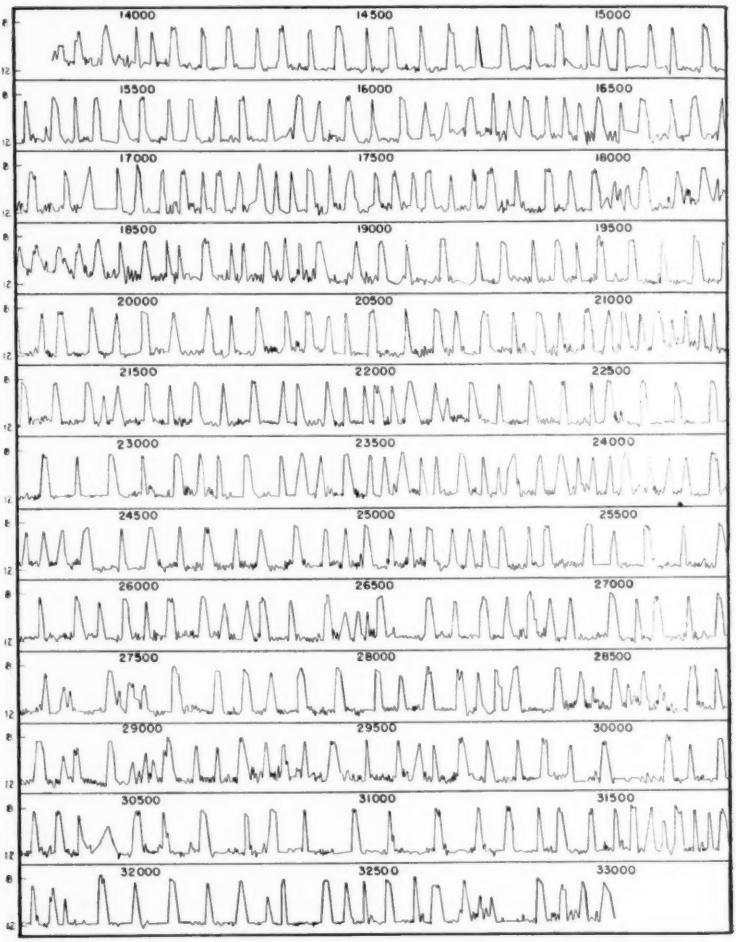
By LEON CAMPBELL, Recorder

A Half Century of Observations of SS Cygni: For slightly more than 50 years—since its discovery by Miss L. D. Wells at Harvard in 1896—the explosive variable SS Cygni has been under almost continuous observation in this country, first by the visual observers at Harvard, later by a few contributing professionals and amateurs, and since 1911 by the members of the A.A.V.S.O. The British, French, and Danish variable star organizations also have assiduously followed the light variations of the star, especially up to the start of World War II.

It is a fair estimate to state that, to date, more than 90,000 observations have been made, on an average of 300 nights per year, or a total of 16,000 separate nights. As far as can be ascertained, not a single maximum has passed unobserved over these years, although at times only one or two estimates may have been secured on a particular maximum.

In the early years there appeared to be an alternation of rapidly increasing broad and narrow maxima, in a cycle of about 50 days, but this situation was not maintained for long. Soon an anomalous type of maximum made its appearance, characterized by a slow increase, which completely disrupted the alternation effect.

For much of the time the star remains rather constant at minimum light, near the 12th magnitude, but as will be seen from an examination of the light curve, there are intervals of time when the light at minimum is subject to decidedly marked irregularities. The star normally increases to nearly the eighth magnitude, but here, too, there are marked deviations from regularity.



LIGHT CURVE OF SS CYGNI, 1896-1949

The observations up to 1933 were collated and discussed in Volume 90 of the *Harvard Annals*. The present note illustrates the variations from 1896 to date (April 10, 1949). The star may be considered as having no regular period, although a mean cycle of 50·4 days appears to persist, with individual cycles

ranging from 20 to 100 days between consecutive maxima. The star has an absolute parallax of 0".32, which indicates a distance of the order of 100 light years, and gives an absolute magnitude of 9.5 at minimum, and 5.7 when at maximum, considerably off the Main Sequence.

UX Ursae Majoris: With his newly constructed photoelectric photometer, Mr. Albert P. Linnell, a graduate student at Harvard, has secured on three nights some observations of the eclipsing binary UX Ursae Majoris (133252) which indicate some startling results. The star has the shortest period of any known eclipsing variable—4^h 43^m—and exhibits intrinsic light fluctuations aside from the main minimum which are cyclic, but irregular in amplitude and period. The mean amplitude appears to be 0^{m}03, with a mean period of four minutes. There is also an asymmetry in the primary minimum with a "platform" or flattening-off, starting at about phase 13.5 minutes after mid-minimum, and lasting about nine minutes. The narrowness of the minimum, and the shortness of the period, appear to support earlier deductions of high mean density for the system.

Faint Minimum of R Coronae Borealis: This erratic variable took one of its deep plunges to minimum recently, dropping to the 14th magnitude about February 12, following a halt, at magnitude 7, in its descent early in December, and another at magnitude 9, later that month.

A New Nova in Scorpio: Word has been received of the discovery of another nova in Scorpio, this one by Professor Erro of the Observatory at Tonanzintla, Mexico. It was found on a plate taken on March 23, 1949, in R.A. 17^h 51^{m}8, Dec. —4° 59′ (Cordoba Chart), at photographic magnitude 7.5. A patrol plate taken there on the preceding night failed to show anything above magnitude 12.5 in the position of the nova, but a plate of March 29 showed the magnitude to be about 9.5, indicating a rather rapid fading in brightness.

A spectrum plate taken with the Schmidt telescope at Tonanzintla shows broad Balmer lines and a conspicuous emission band around λ 4641.

Since the star is rather far south for observers in northern latitudes, observations will doubtless be confined to observers near and south of the equator.

AAVSO Spring Meeting: The 38th Annual Spring Meeting of the AAVSO is to be held at Ladd Observatory, Brown University, Providence, R. I., on May 27-28. Dr. Harries-Clichy Peterson of the Finn Ronne Antarctic Expedition will lecture on Friday evening on "Scientific Research in the Antarctic." Following the business sessions on Saturday, a trip to the Seagrave Observatory at North Scituate is planned.

Observations received during February and March: A total of 7,298 observations—3,241 in February and 4,057 in March—was received from 73 observers, as follows:

Observer	February—1949—March No. Var.	No. Ests.	No. Var.	No. Ests.	Observer	February—1949—March No. Var.	No. Ests.	No. Var.	No. Ests.
Alnert	48	450	42	170	Bufkin	..	..	6	7
Ancarani	22	37	20	29	Cain	3	3	8	8
Ashbrook	..	..	1	8	Caraioryis	6	6	8	8
Bajocchi	11	14	15	32	Chandra	120	150	157	291
Bappu, M. K.	..	..	40	78	Charles	..	..	6	8
Bartha	..	..	8	38	Chassapis	10	35	17	25
Bartlett	1	3	2	13	Cilley	23	50	..	..
Bernasconi	13	202	..	..	Cragg	..	..	105	105
Bogard	57	118	49	116	Daley	..	..	4	8
Buckstaff	5	7	5	8	Darling	..	..	9	16

Observer	February—1949—March No. Var.	No. Ests.	No. Var.	No. Ests.	Observer	February—1949—March No. Var.	No. Ests.	No. Var.	No. Ests.
Darnell	3	12	..	..	Miller	30	33	45	73
Dillon	3	4	2	4	Oravec	55	114	65	166
Drakakis	7	37	7	96	Parks	17	24	14	14
Edelenyi	3	3	..	..	Pearcy	26	26	75	75
Escalante	104	155	86	110	Peltier	154	181	127	147
Estremadoyro, V. A.	3	4	4	6	Penhallow	..	..	24	42
Fernald	221	336	283	600	Pierson	32	56	72	109
Focas	..	..	22	22	Rakosi	3	12	13	25
Ford	..	..	15	16	Renner	..	..	36	36
Greenley	57	108	54	108	Rich	6	7	..	..
Hardi	2	3	..	..	Rosebrugh	18	80	18	109
Hartman	97	102	160	165	Rusho	..	..	3	7
Herbig	1	3	1	9	Simpson	..	..	9	17
Herring	..	..	16	18	Svolopoulos	6	6	..	..
Holloway	4	5	..	..	Taboada	143	149	72	72
Jager	..	..	8	23	Tifft	10	10	21	21
Kardashian	..	..	4	7	Toth	..	..	8	132
Kantor	..	..	8	19	Venter	11	11	..	..
Kelly	..	..	7	11	de Vries	..	..	11	25
Kirchhoff	..	..	13	21	Waters	3	3	2	2
de Kock	91	383	93	365	Webb	23	27	20	20
Lacchini	50	93	56	76	Wells	..	..	3	3
Lankford	7	17	4	18	Werntz	..	..	12	15
Leinbach	..	..	2	2	Weitzenhoffer	..	..	4	15
Lowder	7	17	18	30	Yamada	15	28	19	60
Luft	6	37	5	20	Zadunaisky	1	4	..	..
Meek	27	76	28	158	73 totals	3,241		4,057	

April 15, 1949.

Comet Notes

By G. VAN BIESBROECK

The year continues to be quiet as far as cometary apparitions are concerned. Last year already three new comets had been discovered at this date while none has been announced since the present year began. There are, however, several comets found in 1948 which are still observable but they are all very faint.

Comet 1948 *d* (Pajdusakova-Mrkos) was recorded here as a small round coma reduced to 15th magnitude on April 2 and 3. It will soon become inaccessible in the evening sky but will again be observable this summer in the morning sky. Visibility has continued for 14 months since discovery.

Comet 1948 *l*, which was such an impressive morning object last November will also soon be lost in the evening sky. It appeared as a very diffuse spot of magnitude 16 at the beginning of this month which extends the visibility over a period of five months.

Periodic Comet Schwassmann-Wachmann No. 1 was found as a nearly stellar image of 16th magnitude on April 2 and 3 while Periodic Comet No. 2 of the same name was reduced to 17th magnitude, still showing a faint wisp of a tail on those dates.

Further efforts at locating the expected Periodic Comet Gale have proved unsuccessful. The computers of the prediction feel quite confident that the

ephemeris should not be much in error and that the object is evidently much fainter than expected. Southern observers have the best chance to recover it.

Williams Bay, Wis., April 11, 1949.

Communications and Comments

Under this heading we shall publish from time to time such material as does not properly fall under any of the established headings of this journal. Here, too, may be found, when occasion arises, articles which the editor may not be willing to give sanction to but which, nevertheless, may be provocative of thought along new lines.

The Possible Significance of Magnetism in Meteorites

In the course of examining a slice of the Sacramento Mountains Iron, found in 1894, it was noted that the slice itself was a magnet. This would seem to be an ordinary and expected finding. Some thought about it, however, aroused the writer's curiosity and some tests were made on the Red River and Canyon Diablo meteorites of Yale's collection at the Peabody Museum.

The Red River iron is a somewhat elongated mass weighing 1,635 pounds and was found to be placed in the museum with its length almost in line with the magnetic meridian. A good compass showed the mass to be strongly magnetized and with a quite regular field. The north pole of the meteorite pointed roughly to the earth's magnetic pole. The Canyon Diablo iron weighing 826 pounds was placed with most of its mass along an east to west line. This mass was also found to be strongly magnetized with the north pole of the meteorite facing west and the south pole facing east. The magnetic field when plotted, showed many irregularities in strength and direction. Spots six inches apart on the side facing the earth's north showed opposite polarities. Some of the variations may be due to inclusions, varying internal structure, and surface irregularities of shape.

The questions arising from these simple observations are these. The iron and nickel of meteorites are of course magnetic materials but just how did they become magnetized? Was it, for instance in the case of the Red River iron, mounting it in a north-south position or in other cases by lying on the ground with its length along a magnetic meridian or in the path of earth currents? Both meteorites had a section cut off one end. Did this cutting with its attendant vibrations induce magnetism? Could they become magnetized in passing through the earth's magnetic field or through the electronic fields of the upper atmosphere or even by the tensions the meteorite produces around itself, in its flight through the atmosphere? Did meteorites become magnetized while in cosmic space by some means? Could this occur for instance by very long-wave radio radiation from the sun, passing close to the sun's magnetic and electric fields or as a result of becoming electrically charged by particles from the sun? Could the magnetism date back to the origin of the meteorites, cometary or otherwise, and shed some light on the life histories of these meteorites? How do the other known meteorites compare in their magnetic properties and especially freshly fallen meteorites?

Though the writer has concerned himself mainly with metallic meteorites, scientific methods of research with delicate instruments will indicate the magnetic properties of any sort of meteorite. Scientists have achieved remarkable

and interesting results in studying the paleomagnetism of the rocks and lavas of the earth. Similar results might be obtained with meteorites.

Is a new field of investigation for meteoriticists indicated?

VINCENT ANYZESKI.

1575 High Street, East Haven, Conn.

General Notes

Dr. Harold L. Johnson, formerly of Lowell Observatory, has been appointed Assistant Professor of Astronomy at the Washburn Observatory, University of Wisconsin.

The Rittenhouse Astronomical Society held its regular monthly meeting on April 8, 1949, in the Randal Morgan Physics Laboratory, University of Pennsylvania. Dr. Leendert Binnendijk, Research Associate, Sproul Observatory, spoke on the topic "The Pleiades Region."

Eastern Telescope Makers Association

This recently established organization shows promise of considerable activity. We are informed that the Council of the Association has recently launched as projects the making of two 16-inch telescopes. A 30-inch telescope is contemplated for the near future, intended to be mounted somewhere in New Jersey. The Association also is planning to publish a magazine devoted to telescope making under the name "Atm's and Astronomy."

The Astronomical Handbook for 1949.—This is the title given to a pamphlet of twenty-five pages, published by The Royal Astronomical Society of New Zealand. In its arrangement and contents it follows other astronomical handbooks. Naturally the times given for the several phenomena are in New Zealand time which is just twelve hours in advance of Greenwich Mean Time. It contains a few good reproductions of sections of the lunar surface, and on the back cover is a good photograph of the Andromeda Nebula. A feature somewhat unexpected to a northern reader is an extended list of south circumpolar objects.

It contains Planet Notes for each month of the year. It is the fifth in the series of similar issues. C.H.G.

Temple University Astronomical Equipment

During recent months Temple University in Philadelphia has been arranging astronomical equipment for student practice in a descriptive course in the subject. This is the first time such a course, designed to satisfy the general liberal arts science requirements, has been offered to its some 5000 eligible students.

Facilities for practice in fundamental astronomy will certainly not be lacking, since, in addition to two bubble sextants and an observoscope, previously purchased by the University, a Navy donation of surplus material included 30 marine sextants, several bubble sextants, theodolites, and telescopic alidades, as well as 3 Canadian "Astrographs," and 4 celestial globes. For more general stargazing

the Navy contribution included 4 two-inch telescopes with 3 tripods, and a four-inch refractor.

This last most useful optical instrument will be supported by a Haines electrically-driven "University Type" equatorial mounting, purchased by the university. Recently delivered by the Haines Co., the mounting is now in process of installation on the roof of Sullivan Memorial Library, a situation which seems to avoid the light-interferences of an urban situation as well as could be expected.

It is hoped that the observatory will be ready for a general Open Night, for students and others interested, early in May.

RAYMOND H. WILSON, JR.
Department of Mathematics, Temple University, Philadelphia, Pa.

Provisional Relative Sunspot Numbers*

1	150	11	154	21	221
2	170	12	185	22	169
3	144	13	178	23	153
4	158	14	164	24	126
5	169	15	175	25	112
6	174	16	172	26	109
7	186	17	182	27	114
8	172	18	199	28	112
9	160	19	200	29	90
10	152	20	210	30	122
				31	120

Mean for March
R = 158.1

*From the Zürich Observatory, furnished by Mr. Neal J. Hines.

Cleveland Astronomical Society Meeting

Before an overflow crowd of nearly 200 members and guests of the Cleveland Astronomical Society, Dr. Otto Struve, long-time Director of the Yerkes and McDonald Observatories and Distinguished Service Professor of Astronomy at the University of Chicago, spoke on "The Evolution of Stars" on March 19. It was Dr. Struve's second appearance at the Warner Auditorium of the Warner and Swasey Observatory as it was he who dedicated the auditorium in October, 1940, with a lecture on "Beta Lyrae," a topic which proved to be related to his second lecture.

The lecture began with a comparison of two groups of astronomers. The first group was described as the "battleship" group, and its members shoot (observe) everything in sight. The second or theoretical group was characterized as being sustained simply by a bubble of pure thought. After a brief discussion of the Bethe cycle and the three fundamental stellar parameters (mass, luminosity, and radius), several spectrum-luminosity diagrams were presented. One of these, due to Kuiper, consisted of near-by stars, another of the Pleiades cluster, and another of the Praesepe cluster. From the scatter near the high-luminosity end of the curves, and from Strömgren's work on stellar evolution, it was suggested that the Praesepe cluster is somewhat older than the Pleiades.

The estimated life of a very young cluster being of the order of 10^7 or 10^8 years, and the estimated life of the galaxy 2×10^9 years, the conclusion is that these clusters and hence individual stars are now being formed and might be observed in the process of formation. It was suggested that the Bok "proto-stars"

or globules condensing from dark nebulae might be these stars. The work of Joy and others in observing emission lines of stars embedded in these dark nebulae was cited as confirmatory evidence. The supposition is that the radiation pressure in these stars eventually exceeds the gravitational attraction, so that a partial vacuum is formed around the star. This might then develop into a star of the type suggested by von Weizsäcker, consisting of a rapidly rotating tenuous outer envelope, an intermediate region in which "ball-bearing" whirl-pools are active, and a dense core slowly rotating as a solid. The envelope is supposedly dissipated into space, the whirl-pools form planets, and the dense core becomes a G-type star of very little rotation. This would account for the well-known drop in the rotational velocity-spectrum relationship near G0. It was also suggested that the low luminosity end of the main sequence forms a "sink" which receives most of the high-luminosity stars in time, and since such stars are slow in transforming hydrogen into helium, they have long lives. This might account for the relatively large number of main sequence stars observed.

PAUL ANNEAR, *Recording Secretary.*
Burrell Observatory, Baldwin-Wallace College, Berea, Ohio, March 31, 1949.

Note on the "Green Flash"

I have observed it not less than fifteen or twenty times. I have usually seen it from ships at sea, mostly in tropical American waters. However, I also saw it very clearly from the window of a Philadelphia apartment building, and once saw it over a distant mountain range in the Arizona desert.

While the phenomenon has varied from the strikingly clear to the dimmest, all the observations that I have made have certain factors in common. In each case the green light has displaced the last lingering fragment of the sun's limb at the instant of disappearance of the latter. It has never lasted more than 1.5 (estimated) or less than 0.5 seconds. There has never been any gap between the disappearance of the sun and the appearance of the green light. The shape of the green light (which has only rarely been definable) gives the impression of a narrow ellipse whose longest axis is horizontal.

From these many observations I have inclined strongly to the belief that the phenomenon is an entirely subjective one. While attempting to see it, one stares fixedly at the vanishing limb of the sun, which, under clear conditions, emits an intense red light. Upon its disappearance, the optic nerve, temporarily dulled to red by this fixity of observation, immediately responds with the complementary color green.

An experiment which I tried tends to corroborate this. My brother, Brandon Barringer, and I stood at the rail of a ship watching for the flash in company of at least twenty other people, all of whom had been warned to look for the phenomenon. The location was north of Puerto Rico and the evening was exceptionally clear. I observed with my left eye and at the same time kept my right eye glued to the telescopic finder of an 8 mm. motion-picture camera. I was thus able not only to make a good observation myself but to record it on color motion picture film. The resulting flash was so brilliant that a universal gasp of astonishment went up from the passengers at the rail. It was perhaps the finest example I have seen and looked like nothing so much as a tiny green traffic light, which glowed for perhaps a second. The film, when developed, was very sharp and clear and gave a beautiful picture of the sunset, but the flash did not appear. The

flash was so bright that I feel confident the film would have picked it up if it had been anything but a phenomenon confined to the optic nerve of the observer.

It has been previously suggested by Russell and others that the flash was caused by differential refraction of the spectral colors of the sun's light in the atmosphere, and that as the red, or straightest, rays disappeared one became momentarily conscious of the other rays, which were more bent and hence could be seen a little later. I do not think that this hypothesis would account for the complete absence of any other color but red in the movie film.

Another reason that I suspect the "spectrum" hypothesis is that no color but green has ever been reported. If the spectrum flashed past the observer's eye immediately after the disappearance of the sun, one would expect some sensation of the other colors, such as yellow and blue. No mention of these has been made in the literature, to my knowledge.

D. Moreau Barringer.

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The Cleveland Astronomical Society

Meeting of April 11, 1949

Sir Harold Spencer Jones, Astronomer Royal of England, was the distinguished speaker at the special meeting of April 11, 1949. Another large crowd of nearly 200 guests and members was present to hear this famous visitor speak on the topic, "The Precise Determination of Time."

The speaker first discussed the various kinds of time. He emphasized the fact that the determination of time has been the principal function of the Greenwich Observatory (of which he is the director), since it was founded in 1675. At that time King Charles II directed the Master-General of the Ordnance to provide, from the sale of old gunpowder, a sum of 500 pounds sterling for the new observatory. Slides were shown of the famous structure built by Sir Christopher Wren, as well as of the new site at Hurstmonceaux, to which the observatory equipment will be moved due to the smog and glare of London. An interesting point brought out in the description of the actual determination of time by the transit instrument, was the fact that Maskelyne (the fourth Astronomer Royal) dismissed an assistant whose observations differed from Maskelyne's. Apparently the differences were viewed as errors rather than personal differences in observers.

The development of refined clocks was traced through the free pendulum clock to the quartz crystal clock now in use. It was brought out that this clock, which has an error of .001 second in 24 hours, is more accurate than the earth in its rotation, the periodic error of which may be as high as .005 second. This clock has been very useful in supplying accurate intervals of time, recently in demand in such fields as radar and communications. Minor disadvantages mentioned are that the quartz crystals tend to "age," and that the installations are complicated and require a good deal of maintenance. The thorough and interesting lecture was concluded with a discussion of the "atomic clock," which may well provide a still more accurate standard of time-keeping by utilizing the natural vibration period of the ammonium atom in gaseous form.

Meeting of April 22, 1949

"Our Galaxy" was the topic of the lecture presented on April 22, 1949, to the usual large group of members and guests of the society in the Warner Audi-

torium of the Warner and Swasey Observatory, by Dr. Freeman D. Miller of the University of Michigan. The society was fortunate in procuring Dr. Miller to speak on this topic, as Milky Way research has long been a specialty of his. The speaker's summary follows.

The phrase "our galaxy" implies, first, that we have some idea of the structure of the Milky Way system, and in addition, that we are aware of other, comparable systems in the observable universe. This talk deals briefly with both topics—parallel explorations of our own and other galactic systems.

The first significant step in the study of our own galaxy was taken by Galileo, when he resolved the Milky Way into innumerable faint stars with his primitive telescopes. Eighteenth century statistical studies by Sir William Herschel led to the conclusion (never later discarded) that the Milky Way is a flattened stellar system. Prior to 1800 astronomers were struck by the resemblance of the "Herschel galaxy" to the many elliptical nebulae. Nevertheless, there was strong evidence against the identity of the Milky Way system as one of these nebulae, and the idea was abandoned for many years.

By 1924 the Cepheid period-luminosity relation, in the hands of Shapley, the discoverer, and of Hubble had served to measure the true extent of the Milky Way system, and to establish the extra-galactic nebulae as stellar systems comparable to our galaxy.

Although our position within the Milky Way, surrounded by clouds of interstellar dust, makes evaluation of the details of the structure of our galaxy difficult, it is possible to compare it with the types of extra-galactic nebulae, and to infer to which class our own galaxy must belong. If, as seems probable, it is a spiral, it should have a massive nuclear star-cloud, and Oort, analysing stellar motions, was able to show that certain systematic characteristics of these motions could be attributed to the gravitational attraction of such a nucleus.

Other methods of probing remote galactic regions, especially in the direction of the center, such as Shapley's galactic windows, and the radio and infra-red explorations of Jansky, Reber, Stebbins, and others were discussed, and some of the outstanding important questions of galactic structure were mentioned briefly.

After this very interesting lecture, the enjoyment of the group was heightened further by the showing of the film, "The Story of Palomar."

PAUL ANNEAR, *Recording Secretary.*
Burrell Observatory, Baldwin-Wallace College, Berea, Ohio.

Book Reviews

Der Sternenlauf, 1949.—A paper-bound brochure of 128 pages bearing the above title has recently come into the office of POPULAR ASTRONOMY. The title does not appear in our German lexicon, but the English equivalent of it probably would be the course of the stars in 1949. The subtitle, indeed, indicates that it is a year-book for friends of the stars and for amateur astronomers. In the preface the double purpose of being helpful to the amateur and of reassuring those interested in astronomy, but fearful of its difficulty, is expressed. In the list of contributors to the year-book are names of some of the leading German astronomers. As usual with such handbooks, it contains a wealth of data and information. It is issued from the Leibniz Press in Munich.

Sweeper in the Sky, the Life of Maria Mitchell, by Helen Wright. (Macmillan Co. 1949. $4.00.)

Miss Wright has written a charming and very readible biography. When you finally lay down the book, you have the impression that you have known Maria Mitchell. In addition, Miss Wright has given a lively picture of life on Nantucket when the Quakers were still predominant and whaling was an important industry. Later with equal authority she describes the early days of Vassar and the movement for women's rights. You realize how much Maria Mitchell accomplished in astronomy and in promoting the education of women.

Astronomical readers would have appreciated more details about her very exact observations. Miss Wright hopes that some day these may be made available. I would have liked to have had one or two of her letters or a page of one of her notebooks printed in facsimile.

The biography starts with Maria's childhood as one of a large family in a Quaker community. Before she was twelve she was helping her father to make his astronomical and meteorological observations, and to correct the chronometers for the whaling ships. At seventeen she and her sister opened a school, but the next year she was offered the position of librarian at the Atheneum. Here she spent her afternoons and evenings for twenty-five years, her mornings in housework, and I hope sometimes in sleep, because every clear night she would be up on the walk on the roof or in the backyard observing the stars with her father. At the library she found time to study and to do her computing. She once said of herself "I was born of ordinary capacity, but of extraordinary persistency." She was a very independent person and she could not brook advice unless she sought it. Maria withdrew from Friend's Meeting when she was about twenty-five because she could not accept the severity and the stern discipline that then was part of Quakerism, though all through her life she was profoundly affected by her early training.

It was on October 1, 1847, while she was making a routine sweep of the sky that she found the comet that was to bring her to the attention of the outside world and to win for her the gold medal given by the king of Denmark. After her mother died she and her father moved to Lynn, Mass. There she continued her observing with her new five-inch telescope that had been given to her by the "Women of America." While living there she one day received an offer from the trustees of the proposed Vassar Female College to be the professor of astronomy and the director of the observatory. One of her letters to Mr. Babcock is most interesting. It was written during the interim before the college was opened. It discusses the problems of evaluating her own fitness and her worth, and the value of teaching young girls astronomy or other sciences. The last twenty-three years of her life, Maria Mitchell spent at Vassar teaching astronomy and observing, and fighting for recognition of equality of the women with the men on the faculty.

During her life she made two trips to Europe where she met many of the leading astronomers. On her second trip she went to Russia and visited the Pulkova Observatory. In 1873 she took what was probably the first series of photographs of sunspots. She also made numerous visual observations of sunspots, of Jupiter and Saturn and their satellites, and of double stars. In 1878 she took five girls to Colorado to observe the total eclipse of the sun.

She must have been a woman of great physical endurance and strong character. She had a great capacity for work, she was forthright and very honest,

and with these virtues went a sense of humor and a feeling of humility. I imagine a frivolous student must have quaked in her shoes and probably did not stay long in her class, but an earnest or an interested student found only sympathy and warm counsel. Today it is a little hard to appreciate how much of a pioneer Maria Mitchell was both in her own observational work and in her teaching of astronomy to girls at Vassar.

Miss Wright has told Maria Mitchell's story well and easily, often using old Nantucket expressions which give a spicy flavor.

HENRIETTA H. SWOPE.
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Voyages To The Moon, by Marjorie Nicolson. (The Macmillan Company, New York City. $4.00.)

This exhaustive and fascinating study of voyages away from the earth to other worlds, usually to the moon or planets but not always, might more accurately have been entitled Cosmic Voyages. Written by a great scholar who was formerly dean of Smith College and who is now professor of English in Columbia University's graduate school, the book is an outgrowth of lectures given at Smith College and at the University of Toronto in 1946. Although the author says she is writing less for the scholar than for her lecture hall audiences, yet for the general reader it is a scholarly treatment in a popular manner of a universally interesting theme. Thirty pages of descriptive bibliography, giving some information on every tale told, adds to the value of the book.

The book is mainly a study of the cosmic voyages as English readers knew them in the 17th and 18th centuries, before the advent of actual balloon ascensions. However, such a study of tales and sources necessarily takes the author backward into ancient times, and actually explores the whole field of literature in imaginary voyages. The author goes back to Cicero, Plutarch, Plato, and Lucian, and takes the reader down through the centuries, showing how the invention of the telescope stimulated creation of tales on voyages to an inhabited moon. She discusses John Wilkins' "Discovery of a New World," which was intended to prove that the moon might be a habitable world. Throughout the book the author calls attention to the satirical themes used by writers such as John Donne, Samuel Johnson, Swift, and Voltaire.

The growth of man's concept of means of transportation to other worlds is traced by Miss Nicholson. She groups her tales according to the methods of travel employed by the writers thus: supernatural voyages, as illustrated by Kepler in his "Somnium," Milton in "Paradise Lost," Henry More, and others; flight "by the help of fowls," one illustration being the trip led by wild swans in Francis Godwin's "Man in the Moon"; flight by artificial wings, of which the author gives numerous examples; and trips by flying machines of many sorts for many kinds of voyages. There are also travelers who employ kites, vials filled with dew, lighter than air balloons, magnetism, electricity, and even apes, to furnish power. The writings of Defoe, Swift, Cyrano de Bergerac, Dante, Chaucer, and Swedenborg are discussed.

After the invention of flying machines and new discoveries in astronomy, cosmic voyages became a combination of imagination and scientific fact. The author mentions the modern tales of Poe, Jules Verne, H. G. Wells, Lewis Carroll's "Alice in Wonderland," "the greatest of cosmic voyages," and C. S. Lewis' "Out of the Silent Planet," "the most beautiful of all cosmic voyages."

To complete her story she mentions such cosmic voyage material as is found in present day comic and pulp magazines and in the Orson Welles radio broadcast, "Invasion of Mars" in 1938.

JANE HAUSER

Carleton College.

The Face of the Moon, by Ralph E. Baldwin. (The University of Chicago Press, Chicago 37, Illinois. $5.00.)

It may seem that the surface of the moon and World Wars I and II have little in common, yet Baldwin has shown, in this valuable addition to lunar literature, a very close connection. If one plots the ratio of the depth to the diameter of well-formed lunar craters, of bomb craters from a variety of World War weapons, and of the known meteoritic craters on earth, they cluster about a curve obeying the relation

$$D = 0.1083d^2 + 0.6917\,d + 0.75$$

where D = log diameter (feet) and d = log depth (feet). For the same three classes of objects, a similar relation holds for the ratio of crater height above the surrounding plain to crater diameter.

From a careful examination of other features of lunar craters—the inner and outer slopes of crater walls, the distribution of craters with and without rays among the dark and light areas of the moon, and their general similarity to terrestrial explosion craters (even to the central peaks)—Baldwin has presented a convincing case for lunar craters as explosion pits resulting from one application of an explosive force. What produced the explosion? Without belligerently defending the theory, Baldwin has marshalled evidence strongly favoring the meteoritic hypothesis, which now rests on a firmer foundation than before. Still, definitive proof is lacking, as it probably will be until a collision of the moon with a large meteorite is actually observed, and the result noted; this, if Baldwin's straightforward and logical arguments hold, will be a new crater—perhaps a new Tycho, complete with a ray system.

But it would be entirely erroneous to regard "The Face of the Moon" solely as a defense of the meteoritic hypothesis. The book is, basically, a clear and well-written exposition of what is known of the physical features of the moonscape. Its reading arouses a sense of excitement and reawakens interest in a subject often regarded as worked over and dead. Many a professional and amateur astronomer will feel, as the reviewer did, that he is taking a *really* good look at the moon for the first time. The moon has so long been virtually abandoned as a field of research by professional astronomers, who have gone to fields much farther away in space and time, that it is refreshing to have this opportunity to reconsider the problems literally looking down upon us on any clear, moonlit night.

The book can be recommended, apart from its provocative presentation of the arguments for explosive origin of the craters, for its wealth of factual information brought together: a fine discussion of terrestrial meteoritic craters, of suggested crater-forming processes, of crypto-volcanic structures on the earth (Baldwin favors the view that these may be fossil meteor craters), of the lunar atmospheric problem, and of the past dynamical history of the moon. Included are maps, photographs, and tables of lunar features, and an appendix containing a technical discussion of such varied topics as the lunar tidal bulge as a function

of the moon's distance, the penetrating power of projectiles, and the calculation of diameters of meteorites "which produced the craters."

There is also an excellent bibliography which, with the manner in which the book is written, indicates that the moon and its problems have been on Baldwin's mind for some time. An important item is, however, missing from the bibliography, undoubtedly because it appeared in a geological journal. It is Dietz' "The Meteoric Impact Origin of the Moon's Surface Features," (*Journal of Geology*, **54**, 359, 1946). In a far more condensed and elementary manner, and obviously quite independently, Dietz has advanced essentially the same thesis for the formation of lunar craters, seas, and lava flows. He has not, however, attempted any quantitative treatment as Baldwin has done, either of the striking geometrical relationship between lunar craters and bomb and meteor craters on earth, or of the mechanism of explosions resulting from high velocity impact. (For the latter, Baldwin has to thank the extensive researches of the Army and Navy—in which he himself had an active part—on bomb craters formed by a wide variety of weapons and bombs, from small artillery shell explosion to the explosions of entire ammunition depots.)

Subject to the inevitable limitations of condensation, the gist of Baldwin's thesis on the formation of lunar features is this: lunar craters and seas form a homogeneous sequence over their entire size range, and hence only one over-all mechanism is needed to explain them. Their form, even to details of central craters, slopes, and amount of material in the crater walls (Shröter's rule: volume of material in crater walls equals volume of crater cup) agrees with that of man-made and terrestrial meteor craters produced by an explosive force applied only once. Volcanism fails to provide such an agreement, but the explosion of meteorites on impact does, and they alone have sufficient energy for this purpose. As Army experiments showed, a relation exists between the geometry of a terrestrial explosion pit and the energy needed to produce it. Extrapolation to lunar craters gives a measure of energies needed for this production, and indicates that a meteorite 1500 feet in diameter and of average velocity could produce a lunar crater 40 miles in diameter. Baldwin also calculates that a nickel-iron meteorite, 10 miles in diameter and travelling 20 miles a second, has sufficient energy to have produced Mare Imbrium and the attendant "grooves" and "splash craters" that appear to emanate radially from the central part of this "sea" and to have been gouged out by low-flying fragments from a central explosion. Both Baldwin and Dietz point to these radial furrows as the result of a large central explosion—probably caused by a collision with an asteroid. The resulting lava flows flooded or obliterated many craters, thus destroying the presumably random distribution of craters present "before the floods came." The well-formed, "new"-looking craters like Tycho and Aristillus, evidently post-mare, should therefore be distributed at random, as indeed they are.

The general style of the book makes for easy reading, but the frequent change of pace from a scientific to a popular, literary expression may prove slightly disturbing to some readers.

"The Face of the Moon" can be highly recommended for professional and amateur astronomers alike as an excellent reference on and treatment of lunar features, and for its extension of the meteoritic hypothesis of the formation of lunar features in the light of the new experimental evidence arising particularly from World War II.

J. A. Hynek.

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